The ecology of weeds and the impact of management on channels in MWEA irrigation scheme, Kenya

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THE ECOLOGY OF WEEDS AND THE IMPACT OF MANAGEMENT ON CHANNELS IN MWEA IRRIGATION SCHEME, KENYA

by

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A Master's Thesis submitted in partial fulfilment of requirements for the award of Master of Philosophy of Loughborough University

September 1997

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ABSTRACT

The growth of weeds in irrigation channels poses significant problems to the managers of such systems, impeding flow and encouraging siltation. Additional problems include health hazards, e.g. schistosomiasis and malaria. This research project aims to describe the plant communities which cause such problems in the Mwea Irrigation Scheme (MIS), Kenya, and to investigate the factors which dictate their presence in relation to appropriate management. The environmental setting of the MIS is described with an emphasis on crop production (75-80% of Kenya's rice) and the functioning of the irrigation scheme which is supplied by water from the Thiba and Nyamindi rivers. The weed management programme is under the Works Department of National Irrigation Board and the farmers who operate a year round schedule of maintenance.

The research is based on: (i) a questionnaire survey of the farmers from the Thiba section of the MIS seeking to identify such aspects as the main weeds species, the problems encountered by the farmers and any uses to which the plants are put; and (ii) an extensive survey of the channels, both irrigation and drainage, within the Thiba section. This survey quantified the plant species and key environmental variables, e.g. pH, electrical conductivity, bank slope and maintenance history, for different categories of channel.

The channel sites were classified on the basis of plant species composition using multivariate analysis. This generated eight groups of sites which were closely related to channel function and position within the irrigation scheme. The analysis also established indicator species for these groups, the autecology of which were investigated through field observations and existing literature. These data were compared and integrated with the output from the questionnaire survey. This led to recommendations for the management of the irrigation scheme based on the ecology of the various channel types, their constituent species and the practical limitations experienced by both the National Irrigation Board and the farmers.
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CHAPTER 1

1 INTRODUCTION

1.1 Statement of problem

Irrigation is a critical aspect of agriculture in sub-Saharan Africa. It augments rain-fed agriculture and creates one of the most productive agricultural systems devised by humans (Chambers and Morris 1973, Ruigu and Adholla 1990). In sub-Saharan Africa irrigation potential estimates vary from 33 to 20 million hectares but only about 5 million hectares are irrigated (FAO 1986, cited by ODA 1993). Irrigation in Africa is estimated as having a productivity value of 3.5 times that of rain-fed agriculture, however, African irrigation has a low efficiency one of the main reasons being weed growth in irrigation and drainage channels (ODA 1993).

In Kenya, the agricultural sector accounts for 30% of the National Gross Domestic Product and 50% of national export earnings. 80% of Kenya's population depends on the agricultural sector. 19% of the total arable land is classified as suitable for agriculture where most crops are planted under rain-fed conditions. Currently, only 1.6% of Kenya is irrigated and 79.4% is unsuitable for agriculture. Kenya's total irrigated land was 356,000 hectares equivalent to 7% of total potentially irrigable land. Of this, 8,800 hectares are under the National Irrigation Board, 3,800 hectares under the Ministry of Agriculture and 23,000 hectares are privately owned. The Mwea Irrigation Scheme (MIS) is the largest single irrigation scheme in country and produces the highest rice yield. It is a government scheme managed by the National Irrigation Board (NIB) (JICA 1989). The productivity of such irrigated land is hindered by the presence of weeds in the irrigation and drainage channels and the problems of these weeds in the MIS in Kenya is serious. This has made it necessary to evaluate methods of weed management with a view to
developing optimal methods in this and other such areas of irrigated agriculture. Knowledge of the weeds and their efficient control will become more important as the potential of irrigation schemes is realised.

This project seeks to contribute to this knowledge which can then be used to better design new irrigation systems, implementing sustainable management and maintenance programmes from inception, and improve maintenance in existing schemes such as MIS.

1.2 The objectives and scope of study
The objectives and scope of study were to:

a. review literature on problems of management and control of weeds growing in irrigation and drainage channels especially in relation to sub-Saharan Africa;

b. identify those weeds growing in the irrigation and drainage channels of the system of MIS;

c. investigate the relationship between the environmental factors and weed species and communities in MIS.

1.3 Hypotheses
The hypotheses for the study were:

1. The composition and percentage cover of plant species in the channels of an irrigation system are dictated by channel type and maintenance regime.

2. The vegetation within a channel undergoes a successional development which is modified or interrupted by maintenance events.
Management of weeds in irrigation and drainage channels in MIS is a major problem to the irrigation authority and the farmers. The farmers currently spend 0.6 hr m⁻¹ yr⁻¹ weeding and de-silting irrigation and drainage channels, NIB manual labourers spend 0.64 hr m⁻¹ yr⁻¹ and a hydraulic excavator 0.16 hr m⁻¹ yr⁻¹. However the weeds continue to be a serious problem reducing the irrigation water available to irrigate rice fields. No previous study has been undertaken to identify the plant species in these irrigation and drainage channels, nor on the most appropriate methods of control. There is no information on current and potential uses of weeds in MIS. Current management is based on knowledge based on the experience from other parts of the World such as Japan and Europe and, given different environmental factors e.g. climate, such approaches may be inappropriate or at best inefficient.

MIS comprises a range of irrigation and drainage channels and supports a complex flora. This study aims to describe the flora of the channels and investigate the factors which dictate the various plant communities. Only by understanding the ecology of the system can efficient and effective channel management be achieved. The investigation will be undertaken in two parts: a questionnaire survey of the farmers and interviews with National Irrigation Board staff to acquire basic information about the scheme, and a field survey of the channels undertaken in four stages:

1. identification of plants in the irrigation and drainage channels;
2. investigation of the distribution of plants and associated environmental factors in the irrigation and drainage channels;
3. exploring the relationship between the identified plant species and communities and environmental factors
4. drawing conclusions regarding management and making recommendations.
Farmers and the NIB will be able to use knowledge from this study in weed control and management thereby enhancing rice production. The results of this study will provide basic information and define future research directions involving weed management in irrigation and drainage channels. More importantly, they will provide the basis for the management, conservation and uses of weeds in irrigation and drainage channels in MIS and other irrigation schemes of Kenya.

MIS, located in Mwea Division Kirinyaga District Central Province Kenya (Figure 1.1), provides an excellent location for this study. MIS is the largest rice growing irrigation scheme in Kenya, and produces 75 - 80% of the country's rice (Modha 1993). The scheme has earth lined irrigation and drainage channels which provide suitable substrate for weed growth and are rich in aquatic and bankside vegetation. The scheme is served by a major tarmac road between Nairobi and Embu as well as several earth roads within the scheme hence access to the study area by road was relatively good. Travel was undertaken by walking, by public transport and occasionally by NIB vehicles. The community use the Kikuyu language which is also my vernacular language. The NIB maintain good records of the scheme and were able to provide essential information about the scheme.
Figure 1.1 Location of Mwea Irrigation Scheme Kenya.

LEGEND
- Project Area
- Capital
- Road
- River
- City/Town

Source: JICA 1989
1.5 Definitions

It is important to define the different elements of MIS at the outset. An irrigation channel conducts irrigation water to the field while a drainage channel removes water and the run-off from a field and out of the scheme. The headworks is the off-take where some of the river water is diverted into the main canal. The constituent channel types are as follows:

Main canal: the main channel that takes water from the headworks to the irrigation scheme and gives rise to branch canals.

Branch canal: a secondary channel that takes irrigation water from the main canal and distributes it to the individual sections.

Unit feeder: a tertiary channel that supplies irrigation water to a whole unit and gives rise to feeders.

Feeder: a quaternary channel which is the smallest irrigation channel and supplies irrigation water directly into the fields.

Field drain: a quaternary channel and is the smallest of the drainage channels in the scheme draining water from the fields and service roads.

Collector drain: a tertiary channel and is the second smallest drainage channel in the scheme which receives drainage water from the field drains in one unit and excess irrigation water from the feeders.

Main drain: a primary channel which is the widest of the drainage channels in the scheme and receives drainage water from the collector drains, branch drains and also excess water from the branch canals.
1.6 Weed problems

Weeds in irrigation and drainage channels are a major problem world wide particularly in the tropics where plant growth rate is high. The main problem associated with these weeds is that they lower the rate of water flow (Crafts 1975, Barrett et al. 1990, Mitchell 1974c, Mitchell 1985; Gupta 1979, 1987) and in certain situations can stop flow almost completely (Gupta 1973).

Weeds increase rate of silt deposition by lowering mean water velocity and trapping sediments thereby reducing the capacity of the channels and also those reservoirs incorporated into the irrigation system (Klingman and Ashton 1982). Weeds can block pumps and intakes and threaten irrigation structures such as bridges, weirs and devices that control and measure water. Weeds facilitate the spread of diseases such as schistosomiasis, malaria, encephalitis and onchocerciasis by providing habitat for the intermediate vectors of such parasites. They also harbour dangerous animals such as crocodiles and snakes (Crafts 1975, Crafts and Robbins 1962b, Fryer 1983, Mitchell 1974b, Mitchell 1985).

Weed seeds in irrigation and drainage channels are transported by water to the irrigated fields where they can grow and compete with food crops such as rice by taking space and by removing nutrients from irrigation water (Crafts and Robbins 1962c, Eggington and Robbins 1920). The vegetation in the channels can also harbour invertebrate pests and diseases which can spread into the fields at certain stages during the cropping period.

1.7 Weed control and management

Weeds causing problems in channels are usually described as aquatic weeds and a number of textbooks have been written dealing with the management of such plants (Murphy and Pierterse, 1990, Mitchell 1985, Gupta 1979, 1987). The concept of aquatic plants is not as useful in the
management of the flora of irrigation channels as it would be for lakes or navigation canals due to the nature of the channels and the species which colonise them. Many of the weed species in the channels can grow out of the water and it is important to note that irrigation channels do not hold water all the year round, drying out when not in use. This is the same for the drainage channels. Consequently the flora is adapted to such conditions and includes species such as Commelina sp., Cynodon dactylon, Panicum repens, Eclipta prostrata and many others which are capable of colonising terrestrial environments. When the channel contains water this flora typically has an emergent life form. Bank weeds which cause problems in irrigation and drainage channels can be truly terrestrial or semi-aquatic vegetation, and are restricted to the banks.

Correct taxonomic identification is necessary for effective weed management and for the purpose of conserving species that have socio-economic values. Different species of weeds are either submerged, floating or emergent/bankside and are likely to require different management options (Barrett, 1978, Barrett et al. 1990). There is hence a need for understanding the biology and ecology of the plant, its role in the system, and the interrelationship of the plant species and the communities together with the management options (Hellawell 1978). Wade (1990) identified the lack of an identification manual for African aquatic plants and few studies of irrigation systems in Africa describe much more than the dominant weed species in the irrigation channels. This study of the irrigation and drainage channels of MIS aimed to provide one of the first detailed descriptions of the species composition of this habitat.
1.8 Techniques for weed management

A fundamental factor dictating the distribution of plant species and communities within a system such as MIS is the impact of weed management. Typically there are four broad control options: biological, physical i.e. manual and mechanical, use of herbicides and environmental control (Barrett 1978, Murphy and Barrett 1990, Gupta 1979, 1987). Extensive reviews of aquatic plant management have been undertaken by Murphy et al. (1990), Gopal (1990), Mitchell et al. (1990) Mitchell and Bowmer (1990), Anderson (1990) and Fernandez et al. (1990) and in some systems, for example, in southern Europe, annual maintenance programmes for irrigation and drainage channels apply manual, mechanical biological and chemical control (Murphy et al. 1990).

1.8.1 Mechanical and manual control

In tropical irrigation systems, weed management in primary and secondary irrigation and drainage channels is often undertaken using both mechanical and manual control which involves physical removal of aquatic macrophyte from the water bodies by cutting manually or by machines.

In manual control, simple cutting tools such as machetes, slashers, scythes, sickles, hoes, chain scythes, and chain knives are employed in all types of channels while grass hooks forks and rakes are used to remove the cut weeds as well as free floating weeds from the water, otherwise the decomposing plant material can cause deoxygenation (Barrett 1978, Gupta 1979, 1987, Mitchell et al. 1990, Robson 1974, and MAFF 1996). In Egypt, simple tools are used in weed management in irrigation systems. The use of these tools is common in African countries and often brings the operator into contact with water which is commonly infested with schistosomiasis carrying snails. Hand tools such as chain scythes can be effective and relatively cheap. Labour cost is very high especially in the developed countries. Other hand tools and machines developed for
aquatic weed management in other water bodies are reviewed by Robson (1974). Dredging can also be achieved using manual labour. For example, to control submerged weeds in Indian irrigation canals, the canals are closed during the summer months for 5-8 weeks period and are drained completely. The weeds dry in the hot sun and then are dug by a large number of labourers. The dry weeds and the mud are put on the channel bank and the water released back into the canal. This method does deprive the farmers of water supply (Gupta 1979).

In mechanical control cutting and dredging equipment for use in irrigation systems have been employed in Africa e.g. draglines, excavators, hydraulic dredgers and back hoes (Mitchell et al. 1990). Dredging mainly removes silt and reshapes the irrigation channels as well as removing most of the aquatic plants and their roots but it requires access to the bank along the water course as well as trained personnel (Robson 1974). Powered aquatic weed cutters, weed rakes, sawfish, boat sweepers and aquatic weed harvesters have been introduced in India to replace the old method of draining the canals (Gupta 1979, 1987). The weed cutting bucket is the most widely used and is capable of cutting both banks and the bed of the channel at one sweep. Other machines are spider tractors and small self propelled pedestrian and ride on machines (Robson 1974). The initial capital and maintenance costs of weed cutting equipment are very high (MAFF 1996) and in developing countries foreign currency is required.

Mechanical techniques provide faster methods of weed removal, can be applied selectively but need to be compatible with crops. Repeated use at key times is needed to deplete the stored foods in rhizomes and kill the perenating organs (Robson 1974). An advantage of cutting weed growth is that the plant material can be used for animal feed, however if left in water, the process of decomposition reduces oxygen concentration and may kill fish and other aquatic animals (Barrett 1978). Cutting and
mowing can be used to control vegetation on the bank. The control achieved by the above methods often lasts only for a relatively short periods owing to the rapid growth of aquatic plants and several cuts may be necessary each season to maintain a weed free water way (Barrett 1978).

1.8.2 Chemical control
Chemical control involves destruction of aquatic macrophytes by use of herbicides. A number of aquatic herbicides have been developed, for example, as listed by Westerdahl et al. (1988b). The herbicides used in the control of weeds in irrigation and drainage channels include 2,4-D (2,4-dichlorophenoxy acetic acid), 2,4-D amine, diquat, endothall, glyphosate, dichlobenil, terbutryne and dalapon (Gangstad 1978, Crafts and Robbins 1962a, Gupta 1979, 1987, MAFF 1996).

Examples of two herbicides commonly used in irrigation systems are glyphosate and acrolein. Glyphosate is a broad spectrum herbicide used for control of most species of emergent and bankside plants. It controls most true floating leaved plants but does not control submerged weeds and algae. It can be used for spot treatment and localised control and the water can be used for irrigation almost immediately after treatment. Some species susceptible to this herbicides are Azolla filiculoides, Lemna minor, Nuphar lutea, Nymphaea alba, Phragmites australis, Typha latifolia, and Panicum repens (Shilling et al. 1990; MAFF 1996).

Acrolein is commonly used for control of submerged weeds in large irrigation canals in Egypt (Mitchell et al. 1990) and in Australia this chemical is widely used to control submerged and emergent weeds in irrigation systems in large quantities to treat 4,000 km of irrigation channels each season (Bowmer 1979; Mitchell and Bowmer 1990). One disadvantage is its toxicity to the aquatic life and fish, however, due to its volatility the water can be used for
irrigation within 48 h of treatment without putting the crop at risk (Bowmer 1979). Diquat is a non-selective contact herbicide used mainly for the control of submerged weeds and some algae (MAFF 1996). The liquid formulation controls most emergent and some floating species and the viscous gel formulation can be used for localised control in still water. The viscous gel is the only herbicide formulation suitable for use in fast flowing water (MAFF 1996). Dichlobenil is a broad spectrum residual herbicide acting mainly through the roots, and controls many submerged weeds such as Potamogeton pectinatus, and some rooted weeds with floating leaves. It can be used for partial treatment in still and flowing water (MAFF 1996). Glyphosate and dalapon are widely used for control of bankside and marginal plants including Typha and aquatic grasses. Diuron is used in control of weeds in smaller on-farm channels.

1.8.3 Biological control
A number of forms of biological control have been employed in the maintenance of irrigation and drainage channels. Some of these rely on herbivores grazing or otherwise feeding directly on the weed species, e.g. herbivorous fish or insects; some rely upon alterations to the physical
environment, e.g. shading, and others involve the deliberate release of pathogens which will damage the target species.

**Grazing**

Grass carp (*Ctenopharyngodon idella*) have been introduced in Africa for the weed control in Egyptian irrigation systems especially the large canals which hold water throughout the season (van der Zweerde 1990). The results have been promising but it has proved impossible to prevent over-fishing of the grass carp by the local population in the densely human populated Nile Delta. In the Imperial Irrigation District in Southern California *Hydrilla verticillata* occupied 50-75% of irrigation canal. More than 90% of the aquatic weeds were cleared by stocking canals with triploid grass carp (Anderson 1990). *C. idella* is also used in India to control submerged weeds in deep, fast flowing irrigation canals which hold water throughout the year.

Grazing can employ different types of livestock, e.g. cattle, goats and horses, to control weeds on the ditch banks (Gupta 1979, 1987). Also snails such as *Marisa cornuarietis* and *Pomacea australis* can control aquatic vegetation although they are not widely used for the fear of causing problems in the rice fields (Gupta 1979).

**Shading**

Plants have been used to shade out aquatic weeds e.g. unicellular algal blooms shade out submerged weeds (Barrett et al. 1990). In Egypt, *Cassuarina* trees were found to inhibit aquatic plant growth in irrigation and drainage channels (Murphy and Pierterse, 1990). *Brachiaria multica* (paragrass) is used to control tall *Typha* in Indian irrigation channels. The grass is also a source of nutrient fodder (Gupta 1979).
Use of pathogens
Disease causing organisms interfere with normal growth of plants. Organisms like *Cercospora rodmanii* have shown beneficial interaction in reduction of *Eichhornia crassipes* in United States (Charudattan 1986).

Biological control has been shown to have a high cost benefit ratio and low energy expenditure where it has been utilised (Spencer and Ted 1975) and it is also environmentally friendly (Njuguna 1991). Njuguna (1991) recommended introduction of biological control as soon as the infestation by *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* is confirmed.

1.8.4 Environmental control
Environmental control involves changing the condition of a water body or the surrounding environment to make it less suitable for plant growth and includes such techniques as altering water depth, the velocity of flow, and planting trees to create shade. The selection of the environmental control techniques is highly dependent on individual sites, e.g. shading by trees is only effective on narrow watercourses running west to east (MAFF 1996). Altering channel depth and cross section tends to be expensive when applied for the sole purpose of weed management. However when dredging or reconstruction work is undertaken for other reasons, the incorporation of environmental weed control in the design should be considered to reduce weed management cost for long term effect (MAFF 1996).

Steep channel banks and high water velocity discourage establishment of aquatic weeds (Gupta 1973). Water depth controls submerged weeds but the effective depth depends on the turbidity of water and the weed species. Plants will grow in depths of 3-4 metres where turbidity is low. Concrete lined channels offer the best weed control however, the construction is very expensive (Gupta 1973).
Drawdown lowers water level exposing part or all the channel bed (Craft and Robins 1962b; Barrett et al. 1990). The aim is usually to expose the vegetation to desiccation or to low temperatures. Increased water levels control emergent weeds by drowning them while the free floating species are washed away. The cost of this control technique is low but it interferes with water use and aquatic fauna (Wade 1990). This method has been used traditionally in India (Gupta 1979, 1987).

Environmental methods of weed control are often more innovative than other types but their reliability may be less than other conventional methods (MAFF 1996).

1.8.5 Integrated control
Because weed plants exhibit various growth forms, integrated control rather than a single control method can offer a better prospect for long term and sustainable management of weeds (Charudattan 1986). 2,4-D and water hyacinth beetle have been used in control of water hyacinth (Gangstad 1978) and grass carp (Ctenopharyngodon idelīa) and water hyacinth beetle have been used in control of Eichhornia crassipes (water hyacinth) in the USA. In the Chambal canal, India, grass carp and mechanical methods have almost completely wiped out submerged weeds (Gupta 1979, 1987). In all the above cases, integrated control has proved more effective than single biological, mechanical or environmental control.

1.9 The ecology of irrigation systems
The main area of research undertaken into irrigation systems concerns the engineering required to establish them and the agriculture and crop production for which they are used. The ecology of the irrigation system itself has received little attention even with regards to the problems associated with disease organisms, the hosts of which live
in the constituent channels, e.g. malaria, schistosomiasis and onchocerciasis.

Research on the constituent flora of irrigation systems suggests that most of the information concerns those species of plant which are regarded as pests at national and international level, e.g. *Eichhornia crassipes*, *Salvinia molesta* and *Typha domingensis.* Whilst this is useful for the agrochemical companies who need to know at which weeds to target chemicals, it sheds little light on the ecological processes occurring in the irrigation and drainage channels. Research into drainage channels in Europe provides the best basis upon which to hypothesise about tropical irrigation systems. For the purpose of this study, design refers to physical appearance of the channel i.e. the width, depth, bank and bed gradient and the function refers to the special activity or the purpose for which the channel was made. Two important factors have described: the importance of channel design and function in dictating the aquatic flora, and the recolonisation and successional processes which occur post-maintenance.

A number of studies in Europe have identified that there are significant differences in weed species composition in drainage channels which have been designed for different functions, e.g. main channels and subsidiary channels (de Lange 1972; Wade 1978 and Palmer et al. 1992). These differences are perpetuated by the maintenance programmes, e.g. weed cutting and dredging which ensure that a given channel fulfils its function. The different types of channels have characteristic plant communities which are able to thrive under a given maintenance regime.

These plant communities are not static but undergo change with time, i.e. a succession of plant communities occurs. This process usually takes a number of years (Wade 1978) and the succession of communities is again typical of a particular channel type. A maintenance event, for example, a weed cut, returns the plant community to an earlier stage
in the succession. After dredging, for example, the recolonisation together with succession of vegetation typically passes through clearly recognisable stages, e.g. open water; submerged and or/floatng; emergent, and on the bank: sparse emergent; dense emergent - abundant/erect. At the dense vegetation stage, the channel performance has deteriorated and requires management if irrigation water is still needed (Figure 1.2). It has been found that a given drainage channel tends to exhibit the same recolonisation and the successional processes after each maintenance event due to the constituent species having become well established in the channel mainly through the existence of propagules, e.g. rhizomes and seeds (Wade 1990). These two ecological factors, function and design, and succession of plant communities, interact with other factors, for example those channels near the coast might be influenced by saline incursions (Palmer et al. 1992). Other examples include impact of grazing, eutrophication and other forms of pollution, and change in land use (Palmer et al. 1992).

1.10 Factors affecting weed growth

Weed growth in irrigation and drainage channels like all other plant growth is affected by the environmental conditions (Mitchell 1974a). These include bank gradient, channel aspect, temperature, pH, rate of water flow, depth of channel, surface area of the channel, dissolved or suspended substances, nature of the substrate, gradient of channel as well as shading (Barrett et al. 1990, Gupta 1973, and Pomeroy and Service 1986). All of these factors were investigated during this study and related to the species growing in the channels.

Mineral salts influence weed growth particularly so in the drainage channels due to salinisation and excess nutrients escaping from the rice fields after fertiliser application. This aspect of specific mineral nutrients available in the channels was, however, not investigated due to problems in achieving and paying for the necessary water analyses.
Electrical conductivity was used as a good indicator of mineral salts dissolved in the water. This measures the intensity of the electric current passing between two electrodes placed in water. In an irrigation system water with a conductivity of 0 to 0.5 Scm\(^{-1}\) is good in relation to crop production; 0.5 to 2.2 Scm\(^{-1}\) is average and over 2.2 Scm\(^{-1}\) is poor and unsuitable for irrigation (Dupries and de Leener 1992). Due to the water movement from primary canal to the fields and then from the fields to the drainage channels and the addition of chemical fertilisers in the rice fields, the water is expected to increase in electrical conductivity as it passes through the system (Dupries and de Leener 1992).

Substrate and water flow are also important factors in macrophyte growth because rooted plants establish where the bottom is stable and different species are adapted to different substrate conditions e.g. mud or sand. Water flow affects the distribution of the substrate particles which also affects the communities (Mitchell 1974b). Deep canals with fast flows do not usually have major plant problems due to the instability of sediments caused by high velocity and washing downstream of the free floating and weakly rooted plants as well as reduction of the light intensity reaching the channel beds due to depth. The problems of large weed beds are mainly in smaller irrigation and drainage channels (Mitchell 1985) which experience periods of low flow or the absence of flow altogether allowing sediments to accumulate and plants to establish.

1.11 Uses of aquatic plants

Apart from the damaging effects of weeds in irrigation and drainage channels they are an important part of the environment particularly in freshwater ecosystem (NAS 1976; Robson 1983). Weeds have been used for human and animal food as well as source of fibre for weaving and pulp for paper making. For example, Ipomoea aquatica a weed of
irrigation systems, provides fodder, manure, leaf protein, alcohol and is used in gas production (Kasasian 1971). More generally, aquatic vegetation provides nutrients for benthic invertebrates, fish and zooplankton (Muthuri 1991). Most Kenyan communities draw food, fibre, medicinal products from plants (Gachathi 1989). Luos and Luhyas gather wild greens from wetlands, which are popular and considered a delicacy and a cure for stomach ailments (Kareri 1991). Although ditchbank weeds create problems in the irrigation and drainage channels, some low growing vegetation, such as Cynodon dactylon, is necessary for bank protection against soil erosion. In weed management programmes it is suggested that the manager should aim at suppressing or eliminating tall or otherwise unwanted vegetation and encourage the growth of soil binding and aesthetically sound vegetation (Gupta 1979, 1987). Grazing of livestock regulated by portable fencing is practised in India (Gupta 1979). Since aquatic plants are increasingly being considered as some of the most productive of plant communities in the world (Muthuri 1991b), it was necessary to investigate current and potential uses of plants growing in the channels by local communities.
Figure 1.2 Stages in the succession of vegetation in irrigation and drainage channels.
CHAPTER 2

2 STUDY AREA AND ENVIRONMENTAL SETTING

2.1 Location and land use

Mwea Irrigation Scheme (MIS) is located in the foot hills of Mt. Kenya, Kirinyaga District, in Central province, Kenya (Figure 1.1). It is 100 km north east of Nairobi. A number of its characteristic features, e.g. the distribution of rainfall, topography and soils are dictated by Mount Kenya (Chambers and Morris 1973).

The nearest town is Embu, in Embu District. The scheme lies between 1,100 m and 1,200 m above sea level and stretches between latitude 0° and 37' south and 0° 45' south and longitude 37° 11' east and 37° 26' east. It covers 12,140 ha of which 5,860 ha are irrigated for rice production (JICA 1988). The rest are used for 32 villages, schools, roads, hospitals dispensaries and forests. The scheme is served by main asphalt paved roads (B6 and B20). It has a network of secondary roads and a total of 60 km of settlement roads which are well developed. The scheme was supplied with electricity, telephones and tapped water to the NIB offices and Ngurubani primary school. Farmers use water from the main canals (JICA 1988).

MIS is the largest of the six NIB irrigation schemes in Kenya. The MIS has a large number of irrigation and drainage channels with a large variety of weed species. Of the six NIB irrigation schemes in Kenya, MIS is the only consistently self supporting scheme, others depend on Government subsidy (Table 2.1).

2.2 Irrigation layout

MIS is divided into two systems, the Nyamindi System which receives water from the Nyamindi River and is the oldest comprising one section, Tebere, and, the Thiba System which comprises four sections (Figure 2.1, Table 2.2) (JICA 1988). Each of the sections is administered by an
Irrigation Officer and varies in size from 1,900 to 3,000 ha and is divided into units, e.g. Unit H1 of the Thiba section (Figure 2.2). These in turn are split into fields.

Table 2.1 The size and budgets of various NIB irrigation schemes in Kenya (units in KSh. 000). (Source: JICA 1988).

<table>
<thead>
<tr>
<th>Schemes</th>
<th>Area (ha)</th>
<th>Income</th>
<th>Expenditure</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mwea</td>
<td>5,860</td>
<td>29,542</td>
<td>28,069</td>
<td>1,473</td>
</tr>
<tr>
<td>Ahero</td>
<td>1,070</td>
<td>4,133</td>
<td>8,647</td>
<td>-4514</td>
</tr>
<tr>
<td>West Kano</td>
<td>670</td>
<td>870</td>
<td>7,970</td>
<td>-7100</td>
</tr>
<tr>
<td>Bunyala</td>
<td>210</td>
<td>788</td>
<td>2,421</td>
<td>1,633</td>
</tr>
<tr>
<td>Perkerra</td>
<td>100</td>
<td>948</td>
<td>5,351</td>
<td>-4403</td>
</tr>
<tr>
<td>Tana</td>
<td>830</td>
<td>2,839</td>
<td>10,019</td>
<td>-7180</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8710</strong></td>
<td><strong>3,912</strong></td>
<td><strong>62,477</strong></td>
<td><strong>-23357</strong></td>
</tr>
</tbody>
</table>

Table 2.2 The names and areas for the various sections which constitute the Mwea Irrigation Scheme, Kenya. (Source: JICA 1988).

<table>
<thead>
<tr>
<th>Name of Section</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tebere</td>
<td>1,300</td>
</tr>
<tr>
<td>Wamumu</td>
<td>1,120</td>
</tr>
<tr>
<td>Karaba</td>
<td>1,070</td>
</tr>
<tr>
<td>Mwea</td>
<td>1,220</td>
</tr>
<tr>
<td>Thiba</td>
<td>1,150</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5,860</strong></td>
</tr>
</tbody>
</table>
Figure 2.1 Layout of Mwea Irrigation Scheme

Source: JICA 1989
Figure 2.2 Typical layout of a unit in Mwea Irrigation Scheme

Source: JICA 1989
Figure 2.3 Water flow in Mwea Irrigation Scheme
(Source: JICA 1988)
Irrigation water is distributed by gravity through a network of open channels. From the headworks on the rivers, water is conveyed via main canals and branch canals into the sections (Figures 2.1 and 2.3). Unit feeders carry water from either main or branch canals to the individual units (Figure 2.2). Within the units, water is supplied to the individual fields by the feeders (Figure 2.2) which arise from unit feeders. Each unit has 100 to 600 paddy fields. A feeder serves two lines of paddy fields one on either side. The standard paddy field measures 0.4 ha (1 acre) and is rectangular with one short side abutting onto the feeder and the other side adjoining the field drain. For example, the Thiba system receives its irrigation water from the River Thiba and Link canal 1 which conveys water from the Nyamandi River (Figure 2.3). Thiba system comprises one main canal which gives rise to four branch canals, each with a capacity of between 2 - 4 m³s⁻¹ and also gives rise to several unit feeders. The majority of the unit feeders arise from branch canals and give rise to feeders, the number of which depends upon the size of a unit. One unit feeder supplies water to one unit (Figure 2.2). A field is served by one inlet from a feeder and has one outlet into field drain which drains the fields and service roads. Excess water from the feeders and water from the field drains flows into a collector drain which is at the bottom of a unit and almost parallel to the unit feeder. A feeder serves between 30 - 100 paddy fields. Where units are located along a river, the field drains and the collector drains deliver their drainage water directly into the river. Elsewhere they flow into branch or main drains.

All the irrigation and drainage channels are designed to handle extra run-off during the heavy rains. Most of the channels were unlined except where they passed through red soils or where there were irrigation structures such as weirs, bridges and off-takes.
The channels are trapezoidal in open section with a maximum slope of 1:400 for the field feeders and 1:800 for the unit feeders (Chambers and Morris 1973).

### 2.3 Soils

MIS is covered by volcanic lava of recent eruption consisting of Thiba basalt which covers 104 km². Thiba basalt hindered the drainage of the rivers Nyamindi and Thiba, leading to accumulation of lake sediments and the formation of black cotton soils. On higher grounds black cotton soils are separated by tongues of red soils (Chambers and Morris 1973). Black cotton soils are suitable for rice growing due to their high water holding capacity and hence suitable for surface irrigation and cheap for construction of canals since they make firm banks which do not require reinforcement. However, they crack during dry periods and swell during the rains making them difficult to work. Most of MIS is underlain with black cotton soil separated by small areas of red soil (Chambers and Morris 1973).

### 2.4 Climate

MIS has an equatorial type of climate with two wet seasons. The long rains last from March to May while short rains fall between October and November (Figure 2.4). The annual mean rainfall is 930 mm, 510 mm of which are concentrated in the long rains season and 290 mm in the short rains season.

Mean annual temperature is 22°C; the mean monthly maximum is 32°C in March and the minimum 15°C in January. Two periods of high temperatures are experienced from February to April and from September to November while low temperatures are from June to August and from December to January (Figure 2.4). Diurnal temperature ranges are considerable.
Solar radiation is high with large seasonal variation ranging from $105 \text{ J cm}^{-2} \text{ day}^{-1}$ to $159 \text{ J cm}^{-2} \text{ day}^{-1}$. Annual average evapotranspiration is $6 \text{ mm day}^{-1}$, the highest being $8 \text{ mm day}^{-1}$ in the month of February while the lowest is $5 \text{ mm day}^{-1}$ in the month of June. Relative humidity is 70% in the morning and 45% in the afternoon per day per year (JICA 1988).
Figure 2.4 Mean monthly rainfall and temperature at Mwea Irrigation Scheme (Source: JICA 1988)
2.5 Natural vegetation

MIS is naturally dry, its natural vegetation is savannah grassland which is unsuitable for agricultural farming. In villages trees such as Grevilea robusta have been planted for timber and firewood. Several fruit trees such as Carica papaya (pawpaw), Mangifera indica (mangoes), Psidium guayaba (guava), Persea gratissima (avocado pear), and Passiflora edulis (passion fruit) are common and make settled areas appear green. These trees have not been planted in the scheme for the fear they might provide habitat for birds which could become pests in the rice fields.

2.6 Population

The society in MIS is made up of mainly Kikuyus. There are 3,240 farmers and their families with an average of eight children per family, each depending on 1.6 ha (4 acres) since close to 94% of the farmers are unemployed. MIS supports a population of 50,000 people which includes not only the farmers and their immediate family but also members of the extended family.

2.7 Organisation and management of Mwea Irrigation Scheme

MIS is managed by the National Irrigation Board (NIB), a Government parastatal established by an Act of Parliament under the Irrigation Act (CAP 347) in 1966. The NIB manages the six irrigation schemes (Table 2.1) and is headed by a General Manager. Each of the irrigation schemes is headed by a Senior Scheme Manager and is divided into eight departments (Figure 2.5). The Works Department is directly concerned with management of the irrigation and drainage channels.

2.8 Cropping practices

MIS aims to produce a single crop of rice per year. The farmers in each section are divided into four rotation (land preparation) groups to avoid competition for
irrigation water and other facilities required by the farmers, such as transport for harvested rice and hired labour. Group one has its fields rotavated first and has longer pre-planting flooding than the last group (Table 2.3). The fields which are flooded for a longer period giving the farmers enough time to level them. This practice also reduced weeds during the rice growing periods due the farmers weeding several times before transplanting.
Figure 2.5 Organisation of Mwea Irrigation Scheme
Figure 2.6 Cropping schedule for Mwea Irrigation Scheme
Figure 2.7 Irrigation water requirement for Mwea Irrigation Scheme
Figure 2.8 Canal maintenance for Mwea Irrigation Scheme, 1992
Figure 2.9 Drainage maintenance for Mwea Irrigation Scheme, 1992
Table 2.3 Rotavation groups preceding land preparation.  
(Source: JICA 1988, 1989)

<table>
<thead>
<tr>
<th>Rotavation Group</th>
<th>Duration of Pre-planting flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>160 - 65 days</td>
</tr>
<tr>
<td>2</td>
<td>100 - 55 days</td>
</tr>
<tr>
<td>3</td>
<td>65 - 40 days</td>
</tr>
<tr>
<td>4</td>
<td>30 - 4 days</td>
</tr>
</tbody>
</table>

Rotavation begins in March and continues until mid-September (Figure 2.6). The fields to be rotavated are soaked in water for three days at a depth of 10 cm before rotavation. Seed sowing begins in the first week of July and transplanting begins in the first week of August. Top dressing and field maintenance takes place in mid September to October. These activities require irrigation water, the highest demand being in October (Figure 2.7) when temperatures are high and most fields are transplanted with rice. Pre-harvest draining begins in early November, three to four weeks before harvesting commences and the fields which will be ready for harvesting are drained.

Rice harvesting begins in December, 120 days from the transplanting date and continues to March. The rice is cut, threshed, wind winnowed and bagged in the field. NIB provided canvas bags, ink, brushes and strings to the farmers, and transports the rice to the stores for the farmers. The rice is dried, weighed re-bagged and becomes the property of the NIB which transports the rice to the Mwea Rice Mills for de-husking.

Two varieties of rice are grown: Basmati and Sindano. Basmati variety yields 60 bags (4.5 tonnes) per ha and Sindano variety 74 bags (5.5 tonnes) per ha. The average crop production is 28,000 tonnes of paddy rice per year which contributes to 75-80% of Kenya's rice yield. The crop value 1992/1993 was Ksh 7,388,024 with an average income per farmer of Ksh 28,000 (Modha 1993).
The NIB prepares the land, give the seeds to the farmers, supplies irrigation water, transports the rice to the stores and buys the rice from the farmers. It also advances each farmer Ksh 2,400 and Ksh 1,600 for transplanting and for harvesting respectively. The NIB pays itself from the sales of rice by deducting from each farmer a total of Ksh. 8,000 for the services rendered.

Rice suffers from leaf miner, stem borer, leaf eating caterpillars and leaf eating grasshoppers which were controlled by using either sumithion or furadan. The insecticides are sprayed by the NIB.

2.9 Weed management

The NIBs Works Department and the farmers at MIS recognise the weeds in irrigation and drainage channels as a serious problem decreasing the efficiency of the farming activity. The Works Department management programme is mainly dictated by the cropping calendar, i.e. the requirement of water in the fields and the availability of labour and the hydraulic machines. The Works Department recognises the periods when irrigation and drainage channels must perform efficiently to supply enough water for rotavation and for the irrigation (Figure 2.6 and 2.7) and maintains the particular system in advance of such critical periods. The management of weeds in irrigation and drainage channels at MIS is summarised in (Figure 2.8 and Figure 2.9). The channels are maintained all the year round. The management is shared between the NIB Works Department and the farmers (JICA 1989, Barker et al. 1996). The Works Department repairs water control gates and is wholly responsible for the management of weeds in main, branch, and link canals, main drains and branch drains by employing both mechanical and manual means of weed control. Farmers are wholly responsible for the maintenance of feeders and field drains employing manual means only. The management of unit feeders and the collector drains is shared between the Works
Department and the farmers. Each farmer is apportioned 40 m of the unit feeder and 40 m of the collector drain serving his unit. The NIB desilts the unit feeders, collector drains and field drains intermittently and the farmers manage the weeds in the unit feeders and collector drains at least twice a year.

Mechanical control uses hydraulic excavators (dredgers) and it is spread throughout the year, minimum use of machine being in November (Figures 2.8 and 2.9). Manual control comprises clearance of weeds and some silt with simple tools such as machetes (pangas), scythes (slashers) and sometimes hoes and spades. The farmers maintain the feeders and field drains serving their holdings. NIB Field Assistants instruct the farmers to maintain these channels three times a year according to the cropping schedule (Figure 2.6) i.e. prior to pre-rotavation flooding, transplanting and top dressing.

The rice fields are ready for rotavation in March (Figure 2.6) and the management of primary irrigation canals together with canals serving the fields to be rotavated commences earlier (Figure 2.8). The dredging of the major drains commences at this time in preparation for long rains in March-May (Figures 2.4 and 2.9). This prevents water logging, the bogging down of tractors and water from overtopping drainage channels and the flooding of service roads. Maintenance of the irrigation system recommences in May in advance of the pre-rotavation flooding of the fields they serve. The drainage systems are maintained in September-October in preparation of short rains in October-November and in preparation of pre-harvest draining.

Main, link and branch canals are maintained three times a year, i.e. dredged once and cleared manually twice. Manual maintenance is done by a team of labourers hired by NIB and usually takes place between June and September for canals and in March-April and October for the drains (Figures 2.8 and 2.9).
2.10 Ecology

In MIS the weed management programme alters the communities by disturbing the channel environment which in turn alters the competitive relationships between plant species. Some plants will have the ability to establish themselves quickly in newly managed channels due to their ability to produce large number of seeds and buds. However, no previous studies of the flora of the channels in the MIS have been undertaken, not even in relation to the more common or troublesome species.
CHAPTER 3

3. METHODOLOGY

3.1 Introduction

Canal irrigation is a direct source of livelihood for hundreds of millions of rural poor in the Third World. Performance of these systems has been disappointing due to lack of enough water particularly at the tailend of the system, the consequence of which has been poor yield and water logging in the tailend of drainage channels (Chambers 1988). Management of the primary and secondary channels has been identified as the central gap in irrigation management and is a key factor in improved irrigation performance. Inadequate maintenance including poor weeding methods and inequitable distribution of irrigation water by the irrigation staff and farmers upstream have also been identified as a contributing factor to the shortage of water at the tail end (Brabben and Bolton 1988; Tiffen 1990). MIS experiences similar problems and a significant part of this has been due to lack of knowledge about the weeds in the channels, the focus of this study.

There had been no previous study of weed management in the channels in MIS nor in any other irrigation scheme in Kenya. Studies of the weeds of channels in other irrigation systems in sub-Saharan Africa had achieved little more than a description of the main weed species. In addition to this, there was no literature on the identification of weeds in the irrigation schemes, not in Kenya, nor in any other African country. Given the extensive flora of the channels in the MIS (over 130 weed species, comprising a number of sedges and grasses), coming to terms with the identification of these species was a significant part of this project. It was essential to identify the weeds as they are the key to the problems of channel management, harbour invertebrate vectors of diseases and provide food for humans and livestock (Mitchell 1974, NAS 1976, Gupta 1979, 1987).
Two methods of data collection were employed: A questionnaire survey of the farmers (referred to as the questionnaire) and interviews with National Irrigation Board (NIB) staff, and a botanical survey and investigation of the flora of the irrigation and drainage channels (referred to as the botanical survey). The questionnaire was used to obtain general data about the irrigation system and more specifically the flora. These data could then be used to compare with the data collected from the channels. The farmers were involved in channel maintenance and it is only right to get the data from them. Such an independent survey enables the farmers to give information they may not have given when asked for it in the presence of other people such as NIB staff for the fear of being victimised.

The botanical survey and investigation were aimed at gaining an insight into the flora of the irrigation and drainage channels and the factors which dictate community composition. It was undertaken through an extensive survey of 61 sites and a more intensive survey of 21 sites over an 11 month period.

3.2. Review of literature

Visits were made to the public university libraries such as University of Nairobi Library, Chiromo library, Kabete Library, Loughborough University library and National Museums of Kenya Library, to gather information on problems of management and control of weeds in irrigation and drainage channels. Reports and journals were read and consultations with experts were made. Several books on problems and management of aquatic weeds exist. Some of such books read were Crafts and Robbins 1962a, Gupta 1973, Klingman and Ashton 1982, Mitchell 1985, Barrett et al. 1990, Chikwenhere and Forno 1991 Massinga 1991, Fryer 1983, Robson 1983, Njuguna 1991, Nyamweru 1991, Ivens 1989.
3.3 Farmers' questionnaire survey

In order to gain an insight into the management of the irrigation system and an indication of the level of knowledge of the weeds occurring in it, a questionnaire survey was designed and completed by members of the farming community. It was decided to survey the farmers of one section of MIS, the Thiba section (see section 3.4.3). This was related to the survey and investigation of the weed flora of the channels. 50 questionnaires were distributed to the farmers from different parts of Thiba section after spending time to convince them to take one each and return a completed copy in a month's time. The questionnaire approach was decided upon as the surveyor had very little time in the field and an interview method would have required much more time.

The questionnaire comprised 53 questions aimed at collecting a range of information about the scheme (Figure 3.1). A prototype questionnaire was tried out on a few farmers and provided the basis for revisions and rewording. A total of 48 questionnaires were returned. (The responses to some of the questions have not yet been analysed and cannot be included in this write up). The NIB staff were interviewed in relation to channel maintenance. The relevant officer to be interviewed was booked two weeks in advance and they were all very co-operative. The interviews were of an open nature focusing on the particular responsibility of the officer.

3.4 The field survey method

Given the paucity of information about the flora of sub-Saharan irrigation systems and the lack of any ecological studies, the field methodology was based on methods used by researchers outside Kenya. It was not possible to survey all the channels in the scheme on account of access difficulties, (public transport was only available along the main road). The survey involved walking in muddy
waterlogged clay soil for long distances, jumping across channels not less than a meter and a half wide (sometimes falling in the water) and collecting different weed species. The tall vegetation exposed the author to dangerous animals such as snakes, hairy caterpillars and stinging and biting insects. However, despite all the problems, the author continued with the research until it was completed.

3.4.1 Identification of weeds

It was necessary to identify the weeds in the irrigation and drainage channels since identification is the first step in effective control methods (Gupta 1973; Wade 1990).

Several preliminary visits were made to MIS and weeds in irrigation and drainage channels from high watermark downwards were identified in the field in accordance to Lind and Tallantire (1962), Ivens (1989), Spencer-Jones and Wade (1986), Brundell (1992), Kokwaro (1972) and Gachathi (1989). In order to develop and extend identification skills, more aquatic weeds were identified in Nairobi Dam, Karia, a small fresh water stream in Muranga District and also from the Ahero irrigation scheme. The weeds identified in the field and those difficult to identify were collected, dried and preserved and then taken to National Museums of Kenya in Nairobi to the Botany Department's National Herbarium for further identification or confirmation.

Sampling of weed plants was carried out in all channel types and in different sections of the scheme. The family, genera, species, English and vernacular names were recorded for each weed species (Annex A).

3.4.2 Relationship of environmental factors and weed growth - a botanical survey

There are numerous methods for surveying the vegetation of water courses. They vary according to the objective of the
survey, available time and expertise, and the nature of the habitat being surveyed. A review was undertaken of methods used for linear freshwater habitats ranging from the extensive investigations of Holmes & Whitton (1977) who used 0.5 km sections of river, to studies of phytosociology in which quadrats are used in the river corridor. Alcock and Palmer (1985) describe a method for surveying the vegetation of drainage channels in the UK. This method is based on previous work in this habitat and is regarded as the standard method for the survey of ditch vegetation (including drainage channels). The method has been successfully applied in a number of studies in a range of locations including the Somerset Levels, England (Wolseley et al. 1984), and Hatfield Chase, England (Wade and Wingfield 1987). Similar survey methodology was used to describe vegetation in irrigation and drainage channels in Chisumbanje, Zimbabwe (pers. comm. C. Ferguson, 1994). Although Alcock and Palmer (1985) state that the sample length of channel should be 20 m, it was considered important to derive the sample length from first principles for MIS given the different flora and environmental conditions. The weed species were recorded along a continuous length of channel, recording the number of new weed species identified every 2 m until no more new weed species were noted. This procedure was repeated for two more channels of different types. The length beyond which no new species were recorded for each of the three channels was noted and from this it was decided that for this study the survey reach should 20 m in length, the same as that for Alcock and Palmer (1985).

3.4.3 Site selection
The botanical survey can be divided into two parts: an extensive survey of 61 sites and a more detailed survey of 21 sites, the latter visited on a monthly to bimonthly basis. All sites were selected from one section, the Thiba section, in order to remove any variation due to, for example, the age of channels in a section or different soil
types. The Thiba section had a total of 627 farmers, a large number of channels of all sizes and functions which were accessible on foot as the main road passed through the section.

Sites were located in such a way as to encompass the range of channel types (main canal, branch canals, unit feeders, field feeders, field drains, collector drains and main drains) and to cover most of the units in Thiba section. The number of each channel type selected depended on the number of channels of that type in the section. For example, there were more field drains than feeders and therefore the majority of drainage channel sites were field drains. The main canal type had the least number of samples since there was only one main canal in the Thiba system.

In order for a sampling section to be representative of that channel, the location of sampling sites in a channel depended on homogeneity of the section with regard to the weed cover, the channel width and the bank slope. The sampling sites were also selected away from hydraulic structures to avoid interference by the water current. Those in field drains and feeders were selected equidistant from either unit feeder or collector drain and always on the fourth paddy field from collector drain upstream or fourth paddy field from unit feeder downstream. This made it easier to relocate the site for resurveying. It also removed longitudinal variation. The sites were chosen to show the spatial variation in channel characteristics and vegetation type. A total of 61 sites were selected and each was surveyed at least once. Thirty two of the sites were surveyed twice, giving a total of 93 samples.

Twenty one of the 61 sites were surveyed at least once a month. At the beginning some of these sites were surveyed twice a month, but this did not give the vegetation enough time for an observable change in vegetation cover to occur. The survey was carried out for 11 months except in February
1995 when no survey was done due to sickness. This survey aimed to show temporal variation, the different rates of recovery in different channel types and identification of management practices. The 21 reference sites covered all seven different channel types and six units in the Thiba section.

### 3.4.4 Survey Method

The survey involved the examination of half the channel lengthways from high water mark (with or without water in the channel), to the middle of the channel and 20 m along the water course. Thorough investigation of the near side was done, recording whether this was the right or left side of the channel as the surveyor faced downstream. The percentage vegetation cover was estimated by eye. It was not possible to accurately estimate the vegetation cover in deep opaque channels but a rake was used to investigate the presence of the submerged weeds. The percentage vegetation cover of the submerged, emergent and floating weeds were all combined and given as out of 100%.

The advantages of the study of the near side were (a) an accurate estimate of vegetation cover as it is easier to estimate the cover in the near half of the channel (some primary channels are about 7 m wide and it would be difficult to estimate the cover for such a wide distance); (b) land use and maintenance operations all of which can affect the vegetation and tend to vary from one side of the channel to the other; and (c) more sites could be visited within a short time since there was less time spent crossing to the other side of the channel.

### 3.4.5 Physical and botanical data collection

The physical and botanical characteristics of each site were recorded on a standard recording sheet. The width of channel at water level was measured using a string fitted with a metal weight at one end and thrown across the channel and the length of string measured. The same string
was used to determine the maximum depth of the channel by hooking the string to a wooden broomstick and the metal end lowered until it touched the bottom of the channel. The depth of channel was determined by measuring the length of wet string. Bank slope was determined using a clinometer, pH using a pH meter or universal indicator by dipping the meter in the unfiltered water. Universal indicator was used when pH meters stopped working). Temperature was measured with a mercury thermometer graduated in degrees centigrade by dipping the thermometer in the water. The electrical conductivity was determined by use of a conductivity meter, and channel aspect by use of a compass. The water velocity was estimated by sprinkling potassium permanganate above the site and recording the time it took to move 20 m, or by use of floating objects. For channels with high weed density shorter distances were used. In the main canal the water velocity in the weed free middle of the channel was estimated and compared with the weedy part of the channel bank using potassium permanganate crystals.

Water colour was recorded by observing water in the channel and recording it as either brown, opaque, clear or milky. The percentage vegetation cover for the near side and for the whole channel were recorded. The weeds were classified as submerged, emergent or floating.

3.4.6 Species record
Species found in the site on the near side were identified and percentage cover determined. Each species was given an abundance rating according to the DAFOR scale:

- D - dominant = 70 - 100% = 5
- A - abundant = 30 - 70% = 4
- F - frequent = 10 - 30% = 3
- O - occasional = 3 - 10% = 2
- R - rare = .3% - 0 = 1

Information from NIB officers and farmers with regard to channel maintenance, time when previously maintained and
the frequency of weeding was obtained and recorded for each site.

3.5 Investigating plant zonation across irrigation and drainage channel
Line transects were made across channel and weeds along the transect were studied by placing four quadrats, each 0.25 m² along the transect. Quadrat A was placed on the bank top, B on the bank slope, C at the junction of the bank and the water level in those channels with flow, or at a point where the bank slope meets the channel bed in case of the dry channels, and D was placed in the middle of the channel (Figure 3.2). In the case of the main and branch canals, quadrant D was estimated because it was impossible to reach the middle of these channels. Half of the channel was studied from bank top to the middle since it was difficult to study both sides without crossing the channels. A total of 30 line transects were studied. The weed species were identified in each quadrat and the percentage cover of each species in the quadrat determined and recorded. The frequency and the average percentage cover of each species in all A quadrats were worked out and recorded. The same was done for all B, C and D quadrats.

3.6 Investigating the current and potential uses of harvested weed plants
The uses of weeds in MIS were obtained by liaising with NIB officers, farmers, and the questionnaire distributed to the farmers in the Thiba Section. Visits to the university libraries and National Museum of Kenya Nairobi Library and Loughborough University Library also provided information on weed uses. Information was obtained from text books such as Watt et al. (1962), Mitchell (1974a), NAS (1976), Gangstad, (1978), Holms et al. (1977), Ayensu (1978), Lindsay (1978), Gachathi (1989), Kareri (1991), Muthuri (1991b) and ODA (1993). Personal observation was also made during visits to MIS.
3.7 Data analysis

Data collection and processing were carried out manually and also with the aid of a computer. In the case of the former, estimates were made of the frequency of the different plant species in the channels of the Thiba section. Weed species were also grouped according to the channel types with the most frequent weed species in different channel types being recorded. These data could be compared with those collected from the questionnaire survey of the farmers. Graphs of percentage weed cover for different sites were drawn and comparison between these data and the physical and chemical characteristics were made (Andrews et al. 1974).

Data from the extensive survey of the 61 sites were classified into channel types on the basis of plant species composition using a TWINSPLAN multivariate analysis. TWINSPLAN (Two Way Indicator Species Analysis) is a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of individuals, i.e. species, and attributes, i.e. sites (Hill, 1979). The sample set of 93 site visits (32 sites having been surveyed on two occasions) was analysed and divided into two groups. The division was repeated a further four times to generate eight groups of sites all of which were more similar to each other than they were to the remainder of the sites. The species composition of all sites is compared by reciprocal averaging. The composition of one site is compared with another to arrive at an average. Each site and composition is then analysed in comparison with this average, thus establishing new averages at every stage until the whole data set is analysed. A two-way table is produced by arranging the sites and the species according to the hierarchy. TWINSPLAN deals with abundance data by treating different amounts of the same species in the same way as it does different species by creating pseudospecies. Each DAFOR score for a given species is treated as a pseudospecies.
TWINSPLAN then carries out indicator ordination which repeats the above process using a minimum number of taxa which are then called indicator species and which are typically present in those sites grouped together relative to other sites. In the first division, the data are divided into two groups identifying indicator species and sites. Then each resulting group is dichotomously divided until no further significant division can be achieved.

The purpose of the indicator analysis is to enable the group members of any site to be predicted from a few species, usually five or less: the fewer species the better.

The division produces a hierarchy of classification, each division with its preferential species identified. These have twice the frequency of occurrence than in the other complimentary group.

Groups of similar sites, end groups, are interpreted by using experience gained in the field to recognise the significance of assemblages of plant species (Palmer et al. 1992) and by comparing the data for the environmental variables such as conductivity and water depth with other end groups.

General statistics, e.g. T-tests and correlation were used to further explore groupings of sites.
THE QUESTIONNAIRE FOR THE FARMERS' IN MWEA TABERE IRRIGATION SCHEME ON MANAGEMENT AND CONTROL OF WEEDS IN IRRIGATION AND DRAINAGE CHANNELS.

1. Farmer Family name

2. Farm Name/Number

3. Farmer's place of birth

4. Age of farmer

5. Number of children

6. Number of children above 18 years

7. Number of children above 13 and below 18 years

8. Farm size

9. Farm location(s)

10. Residential village

11. Do you have other farms apart from rice paddy

12. Location of other farms

13. Size of other farms

14. List crops grown in other farms

............................
15. Do you make use of banding along your paddy as farms ......

16. What do you grow? ..........................................................

17. Any damage done to the banding by the farm.
   YES
   NO

18. If Yes, what damage? ......................................................

19. How serious is the problem of damage?
   Moderate   Serious   Very serious

20. Is the head of family (male) employed elsewhere?
   YES
   NO

21. Who does the weeding of paddy?
   Men
   Women
   Children

22. Who weeds the main and Branch canals?
   NIB
   Farmer's wife
   Labourers
   Farmers children
   Farmer

23. Who weeds the small channels. (Field feeders, field drains)
   NIB
   Farmer
   Labourers
   Farmers wives
   Farmers children
   Boys
   Girls

24. Who weeds collector drains and unit feeders.
   NIB
   Farmer
   Farmers children
   Boys
   Girls

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25. Do you have permanent employee to work in your farms?
   YES NO

26. How did you get the land?
   Inherited from parents
   Allocation by NIB
   Bought from previous farmer
   None of the above

27. Do you keep any livestock?
   YES NO

28. If yes.
   How many heads of cattle do you have? ........................................
   How many donkeys, ..............................................................
   How many sheep .................................................................

29. Where does your livestock graze?
   Zero grazing
   Along the roads
   Along the banding
   Tether where there are no rice fields

30. Any specific person who take care of cattle
   YES NO

31. If yes - Who
   Boys
   Girls
   Head of family
   Wives

32. Does presence of livestock in paddies create any problems to the farmers
   YES NO
33. If yes, what are the problems?

34. Do the benefits outweigh the losses incurred by farmers due to presence of livestock?

  No
  Yes

35. If yes, what are the benefits of keeping livestock?

  Cattle
  Donkey
  Sheep
  Goat

36. How often do you weed the irrigation and drainage channels?

  Once a year
  Twice a year
  Three times a year
  Four times a year
  Once every month

37. How do you remove the weeds?

  a) Manually by
     Hand pulling
     Cutting with a pangas
     Slashing with a slasher
     Hoeing

  b) Chemically
     Give name of chemical

  c) Biologically
     Give the organisms used

38. Why do you occasionally allow weeds to grow in the channels?

  To provide fodder for livestock
  To provide vegetables for my family
  To provide medicine
  They are expensive to eradicate
39. If you are NIB would you allow livestock in Mwea irrigation scheme?
   YES  Give reasons .................................................................
   NO   Give reasons .................................................................

40. Do weeds reduce rate of water flow in the channels?
   YES  I do not know
   NO

41. Are the weeds in irrigation channels the same as the weeds in the fields?
   YES  Some are
   NO

42. List the name of TEN weeds that are common in your paddies beginning with the most common and end with the list common

   1.  
   2.  
   3.  
   4.  
   5.  
   6.  
   7.  
   8.  
   9.  
   10. 

43. List the TEN weeds in the channels in order of abundance

   1.  
   2.  
   3.  
   4.  
   5.  
   6.  
   7.  
   8.  
   9.  
   10. 

44. Which of the above weeds are most difficult to remove?

   1.  
   2.  
   3.  
   4.  
   5.  

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5. Are weeds dispersed by water from channels to the fields

46. Do you catch fish?

YES

NO

47. Where do you catch them?

Main channels

Paddies

Both main and small channels

Ponds

48. What types of fish do you catch?

49. Any management of fish

50. Where do they lay eggs?

51. Which are the commonest diseases do you suffer from, list them in order of priority

1.

2.

3.

4.

5.

52. Where does your water for domestic use come from?

Thiba River

Branch canal

Main canal

If other specify

53. Is there any need of toilets in the farmer?

YES

NO
Figure 3.2 Zonation in the irrigation and drainage channels in Mwea Irrigation Scheme

Key
A - Terrestrial Zone (bank top)
B - Transitional Zone (bank slope)
C - Aquatic Zone (water level)
D - Aquatic Zone (middle of the channel)
CHAPTER 4

4. RESULTS

4.1. Introduction

The results are presented by firstly considering the cropping cycle and weed management which is in large measure responsible for the pattern of channels types. The management of the different channel types is described along with other weed management methods used in different parts of the MIS, e.g. grazing, based in the main on the results of the farmers' questionnaire survey and also on personal observations of MIS.

Of the 134 species recorded in MIS, only a relatively few are regarded as serious weeds. These species are identified from the farmers' questionnaire survey and the botanical survey. This leads on to an exposition of the results of a multivariate analysis, TWINSPAN of the botanical survey of the Thiba section of MIS.

The remainder of the chapter is given over to the description of the various environmental factors which were measured at each of the sites in the botanical survey.

4.2. Cropping cycle and weed management in Mwea Irrigation Scheme

Weed management in MIS was mainly dictated by the cropping schedule (Figure 2.6). Rotavation began in March and all the irrigation channels for those fields to be rotavated were cleared in March-April to allow for maximum discharge. Long rains came in March-May which made clearance of the drainage system mandatory in order to avoid flooding of the service roads and fields which would lead to bogging down tractors. Seeds were issued to the farmers by the NIB in the first week of July and before then all the channels were cleared to avoid seedlings being infected with diseases harboured by
weeds or being eaten by insect pests present in the weeds, hence the June-July clearance. In September and early October, rice suffered from lack of water due to high water demand in all sections and less water in the rivers due to drought (Figures 2.4, 2.6 and 2.7). This was the period for weeding and top dressing which also required water. To convey the little amount of water available, irrigation channels were managed in September-October (Figure 2.8). Drainage channels were also cleared at this time to drain the run-off during the short rains in October-November (Figures 2.4 and 2.9). The farmers who did not weed their drainage channels at this time weeded them during October-November for preharvest draining. The weed management in Mwea Irrigation Scheme is summarised in Table 4.1
<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>ENVIRONMENTAL VARIABLES</th>
<th>FLOW REGIME</th>
<th>PRINCIPAL WEEDS</th>
<th>MAINTENANCE ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main canal</td>
<td>Width water level 8.2-4.8 m Mean width 6.7 m Depth 1.1 m-0.66 m Temperature 23-18°C</td>
<td>Flow year round. Supplied irrigation and domestic water.</td>
<td>Panicum repens Commelina sp. Cyperus dives Typha latifolia Desmodium sandvicensis Paspalum scrobiculatum</td>
<td>Mechanicalbr Excavated once a year by NIB March-April prior pre-rotation flooding or Typha latifolia Desmodium sandvicensis Paspalum scrobiculatum ManualNIB slashed twice a year November-December</td>
</tr>
<tr>
<td>Branch canal</td>
<td>Width water level 7.98-1.4 m Mean width water level 1.6 m Depth 1.0-0.36 m Temperature 27-19°C</td>
<td>Flowed all the year round supplying water for the irrigation and for the domestic use.</td>
<td>Panicum repens Leersia hexandra Commelina sp. Cyperus dives Typha latifolia Desmodium sandvicensis Ludwigia abyssinica commelina sp.</td>
<td>Mechanicalbr Excavated once a year July-August. ManualSlashed twice by NIB March-April, September-October before top dressing.</td>
</tr>
<tr>
<td>Unit feeder</td>
<td>Width water level 1.82-0.0 m Mean width water level 1.29 m Mean width 0.27-0.0 m Temperature 38-18°C</td>
<td>Flow depended on cropping programme and had a lot of water in November. Some dried out between December to January</td>
<td>Leersia hexandra Paspalum scrobiculatum Commelina sp. Cypernodon dactylon Ageratum conyzoides Echinochloa pyramidalis Ludwigia abyssinica commelina sp.</td>
<td>Mechanicalbr Excavated intermittently between December-February prior pre-rotation flooding. Manual40m per farmer, managed 3 times a year, February-March, prior pre-rotation flooding, June-July Prior transplanting and September-October.</td>
</tr>
<tr>
<td>Feeder</td>
<td>Width water level 1.58-0.0 m Mean width water level 0.87 m Depth 0.37-0.0 m Temperature 31-19°C</td>
<td>Flow depended on cropping programme. More water during rotation and irrigation period i.e., April-September-November. Some dried out between December to January.</td>
<td>Leersia hexandra Paspalum scrobiculatum Cypernodon dactylon Ageratum conyzoides Commelina sp. Acama caudalhiza Indigofera schincheri Sisochroastes maghiana</td>
<td>Mechanicalbr Excavated once a year July-August. ManualSlashed twice by NIB March-April, September-October before top dressing.</td>
</tr>
<tr>
<td>Field drain</td>
<td>Width water level 1.2-0.0 m Mean width water level 0.37-0.0 m Depth 0.35-0.0 m Temperature 37-19°C</td>
<td>Flow was high during the heavy rains during pre-harvest drying. Dried from January to March. Some dried for six months. With flow from March to December.</td>
<td>Leersia hexandra Panicum repens Ageratum conyzoides Cyperus repens Acama caudalhiza Indigofera schincheri</td>
<td>Manualbr They were wholly maintained by the farmers three times a year in March-April, and pre-rotation flooding June-July before transplanting, and September-October before top dressing.</td>
</tr>
<tr>
<td>Collector drain</td>
<td>Width water level 3.18-0.0 m Mean width water level 1.69 m Depth 0.49 m-0.0 m Temperature 36-20°C</td>
<td>Flow depended on cropping programme. Most of them had water except after the pre-harvest drying with water flow between March to December.</td>
<td>Leersia hexandra Ludwigia stolonifera Paspalum scrobiculatum Cypernodon dactylon Fluchea bequeri Cyperus sp.</td>
<td>Mechanicalbr Excavated by NIB intermittently in May-June. Manualbr Maintained three times a year by farmers. May-June, July-August and November-December prior pre-harvest drying.</td>
</tr>
<tr>
<td>Main drain</td>
<td>Width water level 6.7-0.0 m Mean width water level 2.3 m Depth 0.68-0.0 m Temperature 30-15°C</td>
<td>Flow throughout the year. High flow between February to December. Highest during the rains and Pre-harvest drying. Slow flow in December to February. Main drains do not dry throughout the year.</td>
<td>Panicum repens Typha latifolia Leersia hexandra Commelina sp. Cypernodon dactylon Echinochloa pyramidalis Echinochloa crus-galli</td>
<td>Mechanicalbr Dredged to remove silt and weeds once per year in February-March or in July-August. ManualSlashed twice a year in July-August and October.</td>
</tr>
</tbody>
</table>
4.3 Weed Management

The weed management in MIS Thiba section is summarised in (Table 4.1). The management and control of weeds was shared between the NIB works department and the farmers. The NIB repaired the gates of all channels and weeded and desilted main canal, link canals, branch canal, branch drain and main drain once a year and desilted unit feeders, collector drains and field drains intermittently by employing excavators and hired teams of labourers to cut the weed manually in main canal, branch canal, branch drain and main drain. Manual management employed use of pangas (machetes), slashers, and occasionally hoes, forks and spades to desilt and reshape the channels. NIB had five excavators which were in operation all the year round except in the event of breakdown. When four excavators were in good working order the NIB was able to desilt the main, branch canals, and main and branch drains once a year. In the events of more excavator breakdowns the main and branch canals were given the first priority.

Each farmer weeded and desilted the feeder next to his paddy fields up to the middle of the channel lengthways. The rest of the feeder was weeded and desilted by his neighbours with whom the feeder was shared. The farmer was also responsible for the field drain along his fields and cutting the weed along the service road next to his farm. In addition, he was allocated 40 m of collector drain and 40 m of unit feeder within his unit to weed and desilt.

The farmers used pangas (machetes) and slashers as the main tools for weeding. They cut the weed plants together with mud and pulled them onto the bank of the channels. When the weed dried it was used as compost. As silt built up, jembes (hoes) were used to cut the silt and it was scooped with spade. The NIB and farmers did not use herbicides as a means of weed control as the herbicides were very expensive and
cheap labour was easily available. There was only one farmer who used glyphosate (Round-up) once as means of weed control in the channels and it cleared *Digitaria* species. The farmers worked in the channels in bare feet, while NIB employees had gum boots. About Ksh. 2 million per year is spent by NIB on management of weeds in major channels.

### 4.3.1. Weed management in main canals (primary channels)

Weed management in the main canals was the responsibility of the NIB (Table 4.1). It was desilted once a year either in March-April prior pre-rotavation flooding or in July-August. Between 50-100 m were desilted by an excavator in eight working hours and all the weeds and roots were removed from the channel. The effective period after dredging was six months. For effective weed management it would have been necessary to desilt twice a year, however, this would have been too expensive due to high initial cost of excavators and the cost of their maintenance. The channel was also slashed by the NIB labourers twice a year in February-March and November. Each labourer was allocated a portion 20-50 m long depending on weed density and he was paid at a rate of Ksh 50 per day. The slashing reduced the height of weeds along the bank of the main canal and slightly decreased the percentage cover. The slashing was effective for only three weeks. Due to its width no part of the main canal was completely covered by the weeds (Figure 4.1). The channel was heavily grazed in August-October.

### 4.3.2. Weed management in branch canals (secondary channels)

The NIB desilted the branch canals once in July-August and slashed twice a year in March-April and September-October (Table 4.1). Some parts were not desilted during the study and others needed desilting twice a year and slashing twice a year due to the fast rate of weed growth. Where the channel gradient was low the water velocity was slow and the rate of
weed growth by percentage cover and siltation were rapid. Despite the fact that this type of channel was wide, sections with slow water flow were completely covered by weeds reducing irrigation water in a whole section such as Thiba section (Figure 4.2).

4.3.3. Weed management in unit feeders (tertiary channels)
The management of unit feeders was the responsibility of both NIB and the farmers. Each farmer was allocated 40 m of unit feeder in his unit (Table 4.1). Although NIB was expected to desilt the unit feeders intermittently, none of the feeders in the study area (Thiba section) was desilted during the study period. The unit feeders were usually desilted between December and March.

The farmers maintained the channels three times a year, in February-March prior pre-rotavation flooding, June-July, before transplanting, and September-October before top dressing and weeding. The effective period of manual maintenance was one month. During the dry fallow period the volume of water was reduced and in some channels there was no water, most of these channels built up high amount of weeds (Figure 4.3). These channels were heavily grazed throughout the year as a result of their being along the MIS roads.

4.3.4. Weed management in feeders (quaternary channels)
The feeders were wholly maintained manually by farmers. The farmers weeded half of the channels up to the middle on the side of their paddy fields. This form of management was effective for three weeks.

On average most farmers maintained feeders three times a year in March-April, prior to pre-rotavation flooding, June-July before seed issue, and in September-October before weeding and top dressing (Table 4.1). Some farmers weeded the
channels four times a year. The NIB did not excavate these channels as they were in the middle of the rice fields. The channels were also not grazed by the livestock during the rice growing period for the same reason. A few farmers spread dry rice straw in the feeders and burnt the straws together with the weeds. Some straw was lain in the channels and used as crossing and in such places weeds did not grow until after two months. Figure 4.4 shows a feeder where rice straw was lain to make a crossing and later burnt.

4.3.5 Weed management in field drains (quaternary channels)
The management in the field drains was the responsibility of the farmers (Table 4.1). The NIB, assisted in desilting when tractors were available mainly in May-June. The farmers weeded field drains three times a year: May-June, July-August, before transplanting and November-December prior to pre-harvest draining. The management was effective for three weeks only. These channels were grazed throughout the year because they were along the roads. The upper reaches of the field drains were not desilted but were slashed poorly reducing height of the weeds but not their percentage cover. Due to the lack of desilting the channels did not drain the water from the field and were dry most of the times supporting a large percentage cover. This type of channel is shown in Figure 4.5.

4.3.6 Weed management in collector drains (tertiary channels)
The collector drains were maintained communally by the NIB and the farmers (Table 4.1). The NIB excavated the channels intermittently when manual desilting was not possible. This took place in April-May with an effective period of two months. Each farmer maintained 40 m of the drain three times a year, in April-May, June-July before seed issue, and in November-December prior to pre-harvest draining (Table 4.1). The management was effective for one month. The NIB plan was
to manage the channel in February-March in preparation for the long rains but this did not happen in Thiba Section during the study. An example of a collector drain is shown Figure 4.6. The farmers managed the channels more frequently (three times a year) than advised by NIB (twice a year) so as to reduce weed density.

4.3.7. Weed management in main drains (primary channels)
The management is summarised in Table 4.1. Main drains were wholly maintained by the NIB. They were excavated once a year in July-August but they were not slashed in Thiba Section during the study although they were supposed to be slashed twice a year.

According to the NIB the main drains were supposed to be excavated once a year in January-February in preparation for long rains in March-May in order to allow vegetation growth to cover banks as a means of controlling soil erosion and to be slashed in July-August and October. Some drains completed a year without desilting or slashing and some parts of drainage system were never managed. Grazing of the livestock throughout the year reduced the height of the weeds in the channel particularly during the drought. The grazing of the livestock had little effect on the weeds such as Typha species, as the livestock preferred grazing on such weeds as Leersia hexandra, Panicum repens and Commelina species. After the channel was dredged it remained effective for six months. A main drain covered with weeds is shown in Figure 4.7.
Figure 4.1  Main canal (site H18 MC 61) with *Cyperus latifolia*, *C. dives*, *Typha latifolia*, *Commelina* sp. and *Panicum repens*

Figure 4.2  Branch canal (site H20 BC 55) with *Echinochloa pyramidalis*, *Panicum repens* and *Polygonum salicifolia* and *Leersia hexandra*

Figure 4.3  Unit feeder (site H3 UF 58) with *Commelina* sp. and *Leersia hexandra*

Figure 4.4  Field feeder (site H1 FF 36) with *Leersia hexandra* and *Commelina* sp.
Figure 4.5  Field drain (H1 FD 56) with *Leersia hexandra*

Figure 4.6  Collector drain (H1 CD 59) with *Leersia hexandra, Commelina sp., Cyperus rotundatus* and *Cyperus latifolia*

Figure 4.7  Main drain (site H6 MD 60) with *Typha latifolia, Panicum repens, Commelina beghalensis, Cyperus dives* and *Cyperus latifolia*
4.4 Methods of weed management in Mwea Irrigation Scheme

The questionnaire survey of the farmers revealed that close to 70% of farmers in MIS recognised the weeds in irrigation and drainage channels as a serious problem in relation to their farming activities. The farmers in MIS weeded irrigation and drainage channels manually. These weeding techniques were observed by the author. The farmers applied different manual methods using different tools depending on weed density and the weed species being managed. In most cases a combination of different methods was applied. A panga was the main tool for weed management often accompanied by pulling. Floating weeds were managed mainly by pulling but a panga was used to cut and disconnect the weeds from the mud where rooted. A panga was also used to cut chunks of mud during desiltation (Table 4.2). The tool was supplied in different sizes and weight and each farmer purchased a tool he or she was able to use comfortably. Slashers were used to slash the weeds mainly along the field drains particularly where desiltation has not been done for a long time. Hoeing, using a jembe (hoe), was applied during the reshaping of the silted channels where it was not easy to desilt using a panga. Forks and spades were also used during desiltation but on a small scale. During manual weed management some weeds were washed down stream by the current despite farmers trying to remove as much weeds as they could from the channels. In channels without flow all weeds were removed. The effective period of manual management in the field drains and feeders was three weeks but in the collector drains and unit feeders it was one month. The rhizomes, roots and tubers were uprooted from the channel beds but not so for the bank weeds as this would have demolished the channel banks as they provided bank protection by binding soil particles. Manual methods of weeding are summarised in Table 4.2. NIB desilted channels mechanically using five excavators and manually by employing labourers who used slashers and pangas for cutting weeds.
Table 4.2 Different manual methods used by farmers in Mwea Irrigation Scheme, Kenya. (Source: Questionnaire, n = 48)

<table>
<thead>
<tr>
<th>Method</th>
<th>% of farmers</th>
<th>Weighted % of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand pulling</td>
<td>34.4</td>
<td>30.3</td>
</tr>
<tr>
<td>Cutting with pangas</td>
<td>50.0</td>
<td>44.1</td>
</tr>
<tr>
<td>Cutting with slashers</td>
<td>2.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Hoeing</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Unspecified</td>
<td>20.8</td>
<td>18.3</td>
</tr>
</tbody>
</table>

The sum of all percentages of the different methods of weeding was 113.5 which was more than 100% because some farmers used more than one method of weeding. The weighted percentage gives a better indication of the importance of weeding methods. Weighted percentage is the percentage value of a method, divided by the total percentage value of all methods, then multiplied by one hundred. (Total weighted percentage of all methods applied add up to 100%).

The frequency of weeding applied by farmers is summarised (Table 4.3). The data from the farmers' questionnaire showed that 50% of the farmers weeded their channels four times a year, prior pre-rotavation flooding, transplanting, top dressing and pre-harvest draining and 35% weeded the channels three times a year.
Table 4.3 The frequency of weeding irrigation and drainage channels in Mwea Irrigation Scheme, Kenya. (Source: Questionnaire, n = 48)

<table>
<thead>
<tr>
<th>Frequency of weeding (yr⁻¹)</th>
<th>% of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>35.4</td>
</tr>
<tr>
<td>4</td>
<td>50.0</td>
</tr>
<tr>
<td>6</td>
<td>4.2</td>
</tr>
<tr>
<td>8</td>
<td>4.2</td>
</tr>
<tr>
<td>12</td>
<td>4.2</td>
</tr>
</tbody>
</table>

In narrow channels such as field drains, mechanical weeding achieved 200 m (400 m²) per 8 working hours, in collector drains 100 m, (310 m²) and in main drains and main canals approximately 50 m (229 m²) per 8 working hours depending on the weed density. Smaller areas, 229m² day⁻¹, were dredged in large channels such as main canals than in the small channels such as field drains, 400m² day⁻¹, because the machine took longer time to drag the silt and weed from the main channels to the bank top.

The NIB labourers slashed a width of about 2 m strip along the channel. The distance cleared by manual weeding depended on the weed density and the amount of silt in the channel. When the weed density was low, the NIB labourers cleared a length of 50 m, (100 m²) per 8 working hours but when the density was high only a length of 20 m, (40m²) was weeded. Farmers manual management cleared smaller areas than NIB.
hired labour as a result of farmers desilting channels manually while the labourers slashed only the tall vegetation and left the percentage vegetation cover almost the same and therefore their management was less effective than that of the farmers'.

4.4.1 Other methods of weed management

Apart from mechanical and manual management, there was a large reduction of weeds in the irrigation and drainage channels due to other methods used in MIS. Some of these methods are discussed below.

4.4.2 Burning

A few farmers spread rice straw along their channels and set them on fire killing the weeds. This was done once a year in February-March after the rice harvest. Most farmers burnt their straw in the paddy fields while a few others left them to decompose providing humus. Burning was more effective in the dry channels than in the channels with water. Where it was applied the channel remained without weed for two months (Figure 4.4). The burning was less laborious and destroyed the disease causing organisms in the straws and weeds. However burning had some disadvantages such as destroying all the weeds along the channel bank and leaving the bank bare hence encouraging soil erosion and water seepage thereby forcing the farmers to rebuild the banks. In addition, it reduced the humus content in the soil and deprived livestock of grazing. The method also produced a lot of smoke contributing to environmental pollution.

4.4.3 Biological control

Large herds of cattle were a common sight in the MIS, grazing in and along many irrigation and drainage channels. The livestock grazed in the paddy fields during the fallow
period. A large herd of livestock had as many as 30 cattle, 10 sheep and sometimes a donkey, all under the care of a young herdsboy. 67% of the farmers kept cattle in the scheme and each farmer and family had an average of three cattle. Thiba section alone had about 1,880 cattle.

During the dry period, i.e. August-October, the livestock grazed the channel vegetation to ground level. The livestock grazed in all the channels except the feeders which were in the middle of the rice fields and were not grazed during the rice growing period. Collector drains, unit feeders and the field drains were heavily grazed compared to the others channels since they were along the roads. Main canals, branch canals and main drains were not as heavily grazed during the rain periods as there were small gardens bordering the channels. After maize was harvested in August, these channels were heavily grazed. During the grazing, the livestock demolished the channels and bundings creating pools in channels and interfering with water flow. They occasionally grazed on rice and encouraged soil erosion due to overgrazing. The livestock polluted water with their faeces and urine as well as stirring mud in the channel making the water unfit for domestic use, however the stirring of mud in the channel made the water opaque hindering growth of submerged weeds.

Livestock, however, were beneficial to the farmer as they reduced the weeds by grazing on them, provided manure, milk, meat, skin, transport and more importantly, bulls were used for ploughing and levelling the rice fields. Farmers sold livestock to raise money for school fees and for a dowry. Some weeds were harvested and transported home to be fed to pigs, calves, and zero grazed cows. Domestic ducks, chicken and turkey fed on aquatic weeds such as Polygonum sp., Ludwigia sp., Leersia sp. and other grasses in the channels around the homestead. Although livestock had a significant
role in the reduction of channel vegetation, there was no deliberate effort by the NIB or the farmers to use or coordinate this method of control.

There were large numbers of wildlife birds which grazed on weeds, weed seeds, the rice crop and small animals. Geese, ducks, African spoonbill, crested cranes, pelicans and cattle egrets were some of the birds observed in the scheme. Some of these wild birds were shot and sometimes poisoned to weaken them, they were then caught and provided meat.

Fish
There were different species of fish in the channels of MIS including *Tilapia* species. Many more small fish were observed concentrated in small weedy channels than in cleared channels. Mature fish were caught in large channels i.e. main and branch canals. Fishing was done by young boys using nets and fishing rods. *Tilapia* species are known to control aquatic weeds (Gangstad 1978). *Grass carp (Ctenopharyngodon idella Val.)* was not present but could be introduced to control aquatic weeds.

Invertebrates
A variety of small beetles fed on *Ludwigia abyssinica* and shoots of *Leersia hexandra* inflicting serious damage, reducing leaves to shreds which in return reduced their growth significantly.

Large numbers of green grasshoppers were evident during rice growing period which fed on rice and aquatic vegetation.

Thousands of small snails were found particularly in the weedy field drains and collector drains. They were concentrated on the rock boulders in the drains and on the surfaces of concrete that made the culverts. These snail were hosts for disease causing organisms responsible for
schistosomiasis (Mavuti 1991). *Marisa cornuarietis* and *Pomacea australis*, although known to control aquatic vegetation (Gupta 1979 and 1987) were not identified, but they could be introduced to control the channel vegetation.

### 4.4.4 Environmental control (drawdown and flooding)

Control water levels in the channels was aimed at supplying irrigation water to different parts of the scheme at different times of the year in order to ensure an equitable distribution of the water. This in turn had an impact on the weed achieving a degree of environmental control.

**Drawdown (drying)**

When irrigation gates were closed most of the channel banks of field drains, collector drains unit feeders and feeders had no water for a period of three to six months and their beds were exposed. Submerged weeds like *Najas grammenea*, *Rotala tenella*, filamentous algae together with floating species such as *Pistia stratiotes*, *Ludwigia stolonifera*, *Marsilea* sp. and *Aponogeton abyssinica* were exposed, drying and dying. In one site on a collector drain, the vegetation cover was reduced from 25% - 20% within 31 days of drying. This effect was short lived as seeds remaining in the channel from a previous drawdown period germinated quickly, e.g. *Polygonum* sp, *Leersia* sp, *Ludwigia abyssinica*, *Ageratum conyzoides*, *Alternanthera sessilis*, *Acmela caulorhiza* and *Eclipta prostrata*. These together with marginal weeds grew quickly and established an extensive draw-down flora increasing the vegetation percentage cover and therefore reducing the effectiveness of drying out.

**Flooding**

Immediately the irrigation gates were opened, the water level in the channels rose, the emergent and terrestrial weeds were
submerged, destroying most of the aerial shoots which led to reduction in the percentage cover. Shoots of *Leersia* sp. and other grasses died when they were submerged for 21 days. The flooding was effective in irrigation channels such as main canal, branch canal, unit feeders and feeders, where the water current was strong enough to force the grasses down and become completely submerged. The water in these channels at the time of the observation was opaque due to silt and there was insufficient light for photosynthesis. There was no weed reduction observed in the drains during flooding.

Flooding swept away the free floating weeds like *Lemna* sp. and *Pistia stratiotes* and uprooted the weakly rooted weeds along the bank. Although the flooding reduced vegetation cover in the channel the NIB did not consciously use it.

The concrete lined channels had low vegetation cover. The vegetation grew after the silt accumulation and from the edge of the lining.

### 4.5 Environmental health and Mwea Irrigation System

The farmers' questionnaire survey revealed that many farmers suffered a number of water related diseases. This affected their productivity and survival. The most common diseases and their frequencies are shown in Table 4.4.

Most of the diseases are water related and suffered by farmers due to partly to their being in contact with the water when weeding channels. Malaria and schistosomiasis (bilharzia) were the most prevalent diseases affecting adult and children in the MIS. Both are prevalent in the inhabitants of irrigation schemes in developing countries (Mwabu 1990) lowering the productivity of the farmers.
Table 4.4 The common diseases and their prevalence in Mwea Irrigation Scheme, Kenya. (Source: Questionnaire. n = 48)

<table>
<thead>
<tr>
<th>Disease</th>
<th>Frequency</th>
<th>% of Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>Schistosomiasis</td>
<td>39</td>
<td>81</td>
</tr>
<tr>
<td>Typhoid fever</td>
<td>25</td>
<td>52</td>
</tr>
<tr>
<td>Amoebic dysentery</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>Coughs and cold</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Headache</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Meningitis</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Hookworms</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Thread worms</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Heartburn</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Trachoma</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Asthma</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fever</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

4.6 Drinking Water
Farmers obtained their drinking water from a variety of sources. According to the farmers questionnaire (Table 4.5), half of the farmers obtained their domestic water from the branch canals and about a third from the main canal. The main and branch canal had fresh water directly from river Thiba. Piped water was supplied to the NIB headquarters and Thiba primary school but not to the villages where farmers lived with their families.
Table 4.5 Sources of drinking water and farmer usage in Mwea Irrigation Scheme, Kenya. (Source: Questionnaire, n = 48)

<table>
<thead>
<tr>
<th>Water sources</th>
<th>% of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branch canals</td>
<td>51</td>
</tr>
<tr>
<td>Main canal</td>
<td>35</td>
</tr>
<tr>
<td>Thiba river</td>
<td>12</td>
</tr>
<tr>
<td>Mukau river</td>
<td>2</td>
</tr>
</tbody>
</table>

4.7 Encroachment of bunding

Farmers who had no other farming lands prepared small plots for vegetables along the bunding near the water and grew tomatoes, kale, spinach and other local vegetables. This damaged bunding and encouraged soil erosion. It also encouraged seepage of water from the fields into the channels. According to the data from the farmers questionnaire about 94% of the farmers were unemployed, with an average of eight children per family and each family depended on 1.6 ha of rice and hence the contributing factor towards the encroachment of bunding utilisation in the production of vegetables. The farmers used irrigation water to irrigate their vegetables.

4.8 Aquatic and terrestrial weeds identified in Mwea Irrigation System

irrigation and drainage channels

There were many weed species and families found in MIS. A total of 31 different plant families and 134 different plant species occur in the irrigation and drainage channels in MIS. Most of those weeds were attached to the channel beds and banks. There were only two species which were identified as free floating namely *Pistia stratiotes* and *Lemna* species and two submerged weed species, *Najas graminea* and *Rotala*
tenella. These two submerged weeds were mainly found in rice paddies and were found only occasionally in channels. Filamentous algae were also classified as submerged at an early stage in their growth but later behaved as a floating weed. The aquatic and terrestrial weeds identified are listed in Annex A.

4.9 Weeds identified by farmers

The farmers identified several weed species which they felt were very common in the channels and posed more problems than others (Table 4.6). The farmers felt that the weeds they identified were also the most difficult to control. The most troublesome weeds consisted mainly of grasses (e.g. *Leersia hexandra*, *Panicum repens* and *Cynodon dactylon*), sedges (e.g. *Cyperus dives* and *Cyperus rotundus*) as well as cattails (*Typha* sp.) and *Commelina* sp. Most of the farmers identified the weeds in their vernacular names and a few of them identified the weeds in using English names while some identified them in scientific names. The researcher had to learn the different names of each weed species by use of different vernacular botanical dictionaries, to be certain which weeds the farmers referred to in their questionnaires. (Some weeds had fewer scores than others and hence lower rank although higher frequency).
Table 4.6 Frequency of the most common weeds in Mwea Irrigation Scheme, Kenya. (Source: Questionnaire, n = 48)

<table>
<thead>
<tr>
<th>WEED SPECIES</th>
<th>RANK</th>
<th>RESPONSE FREQUENCY</th>
<th>% FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leersia hexandra</td>
<td>1</td>
<td>38</td>
<td>79</td>
</tr>
<tr>
<td>Typha sp.</td>
<td>2</td>
<td>22</td>
<td>46</td>
</tr>
<tr>
<td>Commelina sp.</td>
<td>3</td>
<td>22</td>
<td>46</td>
</tr>
<tr>
<td>Cynodon dactylon</td>
<td>4</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td>Ludwigia stolonifera</td>
<td>5</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>Cyperus dives</td>
<td>6</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>Cyperus rotundus</td>
<td>7</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Marsilea sp.</td>
<td>8</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Echinochloa colona</td>
<td>9</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Digitaria sp.</td>
<td>10</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Schoenoplectus sp.</td>
<td>11</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Panicum repens</td>
<td>12</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Polygonum sp.</td>
<td>13</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Sphaeranthus sp.</td>
<td>14</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Alternanthera sessilis</td>
<td>15</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Ludwigia abyssinica</td>
<td>16</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Echinochloa pyramidalis</td>
<td>17</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Ludwigia jussiaeoides</td>
<td>18</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Aponogeton abyssinica</td>
<td>19</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Ottelia exerta</td>
<td>20</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

4.10 Extensive channel survey data
Several weed species were identified in different channels. Table 4.7 reveals that the grasses are the most common weeds constituting major problems in the channels. Leersia hexandra, Commelina sp. Cynodon dactylon and Panicum repens are the most widely distributed weeds in the channels.
Table 4.7. Distribution of principal weed species in Mwea Irrigation Scheme, Kenya. (Source: Botanical survey. Total number of samples with weeds = 291)

<table>
<thead>
<tr>
<th>WEED SPECIES</th>
<th>FREQUENCY (n = 313)</th>
<th>FREQUENCY (%)</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abutilon guineense</td>
<td>47</td>
<td>16.2</td>
<td>20</td>
</tr>
<tr>
<td>Acmella caulorrhiza</td>
<td>73</td>
<td>23.6</td>
<td>9</td>
</tr>
<tr>
<td>Ageratum conyzoides</td>
<td>120</td>
<td>41.2</td>
<td>4</td>
</tr>
<tr>
<td>Ajuga remotia</td>
<td>56</td>
<td>19.2</td>
<td>15</td>
</tr>
<tr>
<td>Filamentous algae</td>
<td>20</td>
<td>6.9</td>
<td>34</td>
</tr>
<tr>
<td>Alternanthera sessilis</td>
<td>46</td>
<td>15.8</td>
<td>22</td>
</tr>
<tr>
<td>Aponogeton abyssinica</td>
<td>11</td>
<td>3.8</td>
<td>40</td>
</tr>
<tr>
<td>Bothriochloa insculpta</td>
<td>60</td>
<td>20.6</td>
<td>13</td>
</tr>
<tr>
<td>Commelina sp.</td>
<td>199</td>
<td>68.4</td>
<td>2</td>
</tr>
<tr>
<td>Cynodon dactylon</td>
<td>128</td>
<td>44.0</td>
<td>3</td>
</tr>
<tr>
<td>Cyperus dives</td>
<td>47</td>
<td>16.2</td>
<td>20</td>
</tr>
<tr>
<td>Cyperus latifolius</td>
<td>32</td>
<td>10.6</td>
<td>30</td>
</tr>
<tr>
<td>Cyperus sp.</td>
<td>51</td>
<td>17.5</td>
<td>17</td>
</tr>
<tr>
<td>Desmodium sandiviscence</td>
<td>42</td>
<td>14.4</td>
<td>23</td>
</tr>
<tr>
<td>Dyschoriste maghiana</td>
<td>56</td>
<td>19.2</td>
<td>15</td>
</tr>
<tr>
<td>Enhydra fructuans</td>
<td>13</td>
<td>4.5</td>
<td>37</td>
</tr>
<tr>
<td>Eclipta prostrata</td>
<td>69</td>
<td>23.7</td>
<td>11</td>
</tr>
<tr>
<td>Echinochloa colona</td>
<td>39</td>
<td>13.4</td>
<td>24</td>
</tr>
<tr>
<td>Echinochloa pyramidalis</td>
<td>36</td>
<td>12.4</td>
<td>25</td>
</tr>
<tr>
<td>Timbrystylis dichotoma</td>
<td>50</td>
<td>17.2</td>
<td>18</td>
</tr>
<tr>
<td>Fluechea bequetii</td>
<td>60</td>
<td>20.6</td>
<td>13</td>
</tr>
<tr>
<td>Indigofera schimperi</td>
<td>70</td>
<td>24.1</td>
<td>10</td>
</tr>
<tr>
<td>Ipomoea cairica</td>
<td>8</td>
<td>2.7</td>
<td>41</td>
</tr>
<tr>
<td>Leersia hexandra</td>
<td>272</td>
<td>93.5</td>
<td>1</td>
</tr>
<tr>
<td>Lemna sp.</td>
<td>12</td>
<td>4.1</td>
<td>39</td>
</tr>
<tr>
<td>Ludwigia abyssinica</td>
<td>82</td>
<td>28.2</td>
<td>7</td>
</tr>
<tr>
<td>Ludwigia stolonifera</td>
<td>75</td>
<td>25.4</td>
<td>8</td>
</tr>
<tr>
<td>Marsilea sp.</td>
<td>36</td>
<td>12.4</td>
<td>25</td>
</tr>
<tr>
<td>Najas graminee</td>
<td>19</td>
<td>6.5</td>
<td>35</td>
</tr>
<tr>
<td>Ottelia exserta</td>
<td>15</td>
<td>5.2</td>
<td>36</td>
</tr>
<tr>
<td>Panicum repens</td>
<td>119</td>
<td>40.9</td>
<td>5</td>
</tr>
<tr>
<td>Paspalum scrobiculatum</td>
<td>94</td>
<td>32.3</td>
<td>6</td>
</tr>
<tr>
<td>Polygonum salicifollum</td>
<td>33</td>
<td>12.3</td>
<td>28</td>
</tr>
<tr>
<td>Polygonum senegalense</td>
<td>50</td>
<td>17.2</td>
<td>18</td>
</tr>
<tr>
<td>Rhynchosia sp.</td>
<td>69</td>
<td>23.7</td>
<td>11</td>
</tr>
<tr>
<td>Rotala tenella</td>
<td>13</td>
<td>4.5</td>
<td>37</td>
</tr>
<tr>
<td>Schoenoplectus sp.</td>
<td>22</td>
<td>7.6</td>
<td>33</td>
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<td>Vigna oblongifolia</td>
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<td>Samples without weeds</td>
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81
Table 4.8. TWINSPAN constancy table for 97 sites and 134 species. (Source: Botanical survey. Constancy classes: V = 80+ to 100%; IV = 60+ to 80%; III = 40+ to 60%; II = 20+ to 40%)

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<td>Species per group</td>
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<td>128 43</td>
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</table>

82
The data collected from the extensive survey of 61 different sites were classified using TWINSPLAN and eight groups were identified (Table 4.8). The groupings are also illustrated in the dendrogram (Figure 4.8). Table 4.8 shows the types of channels and environmental variables associated with the groups of sites, and summarising the type and diversity of species found in them. For example, the most frequent weeds in group 1 were Najas graminea, filamentous algae and Leersia hexandra. These channels were narrow and shallow and the percentage cover was less than 10% due to recent management. The table shows that some weed species were found in only a few groups e.g. Typha sp. in groups 5 and 6 and Najas graminea in group 1, while Leersia hexandra, and Commelina sp. were distributed in all channel types. The most floristically diverse channel is group 5 with a mean of 18 species, followed by groups 6 and then 4. The least floristically diverse channels are groups 1 and 2 with a mean of six species each.
4.11 Intensive channel survey data

The results of the repeated channels survey are displayed in the Table 4.9. It shows a preference in some weeds for specific habitat, e.g. *Typha latifolia* in the main drains, *Echinochloa pyramidalis* in the branch canal and in the main drains channels which were managed infrequently, but absent in some channel types such as unit feeders and field drains e.g. channels frequently desilted during the management. *Leersia hexandra*, *Panicum repens* and *Commelina* sp. were distributed widely due to their structural adaptation (Annex C).

Out of a total of 134 weed species identified in MIS (including 18 sedges and 21 grasses), there are six species of grasses, four sedges and 14 broad leafed weed species which constitute the most frequent weeds as identified by the farmers' questionnaire, the intensive and the extensive channel survey (Table 4.10). Overall, it is the grasses which are the most problematic weeds. Although there are relatively few species, their frequencies and percentage cover are much higher than those of the broad leafed weeds.
Figure 4.8 Dendrogram showing TWINSPLAN subsets and indicator species

- Paspalum scrobiculatum
- Ludwigia stolonifera

N = 24
- Euchea bequertii

N = 4
- Jlas graminea
- Commelina sp. 1
- Leersia hexandra

N = 20
- Fimbristylis dichotoma
- Sphaeranthes napierae

N = 34
- No indicator

N = 6
- Ageratum conyzoides
- Alternanthera sessilis

N = 4
- Cyperus sp.

N = 8
- Typha sp.
- Cynodon dactylon
- Cyperus dives
- Marsilea sp.

N = 23
- Ludwigia abyssinica
- Polygonum senegalense
- Echinochloa pyramidalis
- Cyperus dives

N = 15
- Ludwigia

N = 40
- Ludwigia stolonifera
- Dyschoriste maghana
- Cynodon dactylon
- Ajuga remota
- Panicum repens
- Asystasp.

N = 15
- Nil indicator

H1 = site location
BC = branch canal; CD = collector drain; F = field feeder;
FD = field drain; MC = main canal;
MD = main drain; UF = unit feeder.

B = second visit to site
N = number of sites
Table 4.9. Scores of principal weeds in different channel types in Mwea Irrigation System, Kenya. (Source: Botanical survey. Constancy classes: >40% = ***; 21 - 40% = **; 1 - 20% = *. FF = Field feeder; FD = Field drain; CD = Collector drain; UF = Unit feeder; BC = Branch canal; MC = Main canal; MD = Main drain)

<table>
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<th>CD</th>
<th>UF</th>
<th>BC</th>
<th>MC</th>
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Table 4.10 Principle weed species in Mwea Irrigation Scheme, Kenya, based on four methods of grouping (Source: Botanical survey and questionnaire. * = Most frequent weeds in MIS)

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<tr>
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</tr>
<tr>
<td>Ajuga remota</td>
</tr>
<tr>
<td>Alternanthera sessilis</td>
</tr>
<tr>
<td>Commelina sp.</td>
</tr>
<tr>
<td>Cynodon dactylon</td>
</tr>
<tr>
<td>Cyperus dives</td>
</tr>
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<td>Cyperus species</td>
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<td>Eclipta prostrata</td>
</tr>
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<td>Fluchea bequertii</td>
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<td>Polygonum senegalense</td>
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<tr>
<td>Sphaeranthus napierae</td>
</tr>
<tr>
<td>Marsilea sp.</td>
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</table>

4.12 Distribution of weeds across the irrigation and drainage channels (zonation)

The line transects studied across different channel types from bank top to the middle of the channel revealed that the weed species distribution across the channel was not even and that some weed species thrived better in parts of channels with water and others in terrestrial condition (Table 4.11). In deep wide channels, e.g. main and branch canals, the middle of the channel lacked weeds. Figure 3.2 shows the different zones studied and in the terrestrial habitat A the dominant weed species were Paspalum scrobiculatum, Cynodon dactylon and Bothriochloa insculpta whereas in transitional zone B on the bank slope, i.e. between the terrestrial and aquatic habitats weed species such as Leersia hexandra,
Paspalum scrobiculatum, Commelina sp. Alternanthera sessilis, Fimbristylis sp. Panicum repens and Cynodon dactylon were the most frequent. In aquatic zone C, the emergent weeds such as Leersia hexandra, Ludwigia stolonifera, Commelina sp. and Panicum repens were the most frequent. In the small channels with flow, the middle of the channel D had very low vegetation cover which was dominated by Ludwigia stolonifera, Aponogeton abyssinica, Marsilea sp., Najas graminea and filamentous algae. In silted major drains, Typha latifolia and Echinochloa pyramidalis were the most frequent species (Table 4.11).
Table 4.11 Distribution of weed species across the channel in Mwea Irrigation Scheme, Kenya. (Source: Channel survey. A = terrestrial (bank top); B = transitional zone (bank slope); C = aquatic zone (water level); D = aquatic zone (middle of channel). % F = percentage frequency; % C = percentage cover)

<table>
<thead>
<tr>
<th>Weed species</th>
<th>A % F</th>
<th>A % C</th>
<th>B % F</th>
<th>B % C</th>
<th>C % F</th>
<th>C % C</th>
<th>D % F</th>
<th>D % C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paspalum scrobiculatum</td>
<td>54</td>
<td>46</td>
<td>27</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cynodon dactylon</td>
<td>45</td>
<td>12</td>
<td>18</td>
<td>6</td>
<td>5</td>
<td>&lt;1</td>
<td>5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Commelina sp.</td>
<td>9</td>
<td>&lt;11</td>
<td>22</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>5</td>
<td>1</td>
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<tr>
<td>Leersia hexandra</td>
<td>8</td>
<td>4</td>
<td>90</td>
<td>54</td>
<td>80</td>
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<td>Panicum repens</td>
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<td>2</td>
<td>13</td>
<td>5</td>
<td>13</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>Bothriochloa insculptre</td>
<td>22</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Eclipta prostrata</td>
<td></td>
<td></td>
<td>9</td>
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<tr>
<td>Ageratum conyzoides</td>
<td>5</td>
<td>&lt;1</td>
<td>9</td>
<td>1</td>
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<td>Ajuga remota</td>
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<td>5</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>Fimbristylis sp.</td>
<td>5</td>
<td>1</td>
<td>13</td>
<td>1</td>
<td>5</td>
<td>1</td>
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<tr>
<td>Fluchea bequertii</td>
<td></td>
<td></td>
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<tr>
<td>Cyperus sp.</td>
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<td>1</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Acmella caulorhiza</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternanthera sessilis</td>
<td>22</td>
<td>&lt;1</td>
<td>9</td>
<td>1</td>
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<tr>
<td>Ludwigia stolonifera</td>
<td>9</td>
<td>2</td>
<td>22</td>
<td>9</td>
<td>18</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aponogeton abyssinica</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marsilea sp.</td>
<td></td>
<td></td>
<td>5</td>
<td>2</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
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<td>Najas graminea</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filamentous algae</td>
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<td></td>
<td>5</td>
<td>&lt;1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typha latifolia</td>
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<td>5</td>
<td>3</td>
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<tr>
<td>Echinochloa pyramidalis</td>
<td>9</td>
<td>6</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

89
4.13 Vegetation regrowth and succession in irrigation and drainage channels

During recolonisation of a channel after a weed cut, successional stages showed a defined cycle of vegetation change and a rapid turnover of species particularly in the narrow shallow channels. The stages of succession were similar to those described for other hydroseres as indicated in Figure 1.2. The vegetation succession and regrowth occurred together in the same channel.

The changes in the channel condition from 'open water' to 'emergent weeds - abundant' was faster in small channels such as feeders, field drains and collector drains than in main and branch canals. Consequently, small channels needed managing more frequently than large channels. A narrow channel required only two months to reach the 'emergent weeds-abundant' stage of succession. At this stage the channel was silted up and allowed very little water to pass through. Most channels which reached the final stage were the field drains particularly the upper reaches which were most of the time dry and supported terrestrial vegetation. The main canals did not reach this stage, even after one year without management.

In shallow channels with clear water the first weeds to grow were the submerged species such as filamentous algae and occasionally, Najas graminea and Rotala tenella. The free floating weeds were Lemna species. Main and branch canals had no submerged weeds because the water was opaque though Lemna was trapped in amongst the marginal weeds.
<table>
<thead>
<tr>
<th>Channel Type</th>
<th>MC</th>
<th>BC</th>
<th>UF</th>
<th>FF</th>
<th>FD</th>
<th>CD</th>
<th>MD</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN CANAL</td>
<td>0.0001</td>
<td>0.06333</td>
<td>0.0367</td>
<td>0.461</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BRANCH CANAL</td>
<td>0.0633</td>
<td>0.959</td>
<td>0.0014</td>
<td>0.335</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNIT FEEDER</td>
<td>0.0367</td>
<td>0.0014</td>
<td>0.0026</td>
<td>0.048</td>
<td>0.609</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEEDER</td>
<td>0.460</td>
<td>0.047</td>
<td>0.0478</td>
<td>0.004</td>
<td>0.493</td>
<td>0.609</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIELD DRAIN</td>
<td></td>
<td></td>
<td></td>
<td>0.49</td>
<td>0.000</td>
<td>0.102</td>
<td>0.006</td>
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<tr>
<td>COLLECTOR DRAIN</td>
<td>0.0001</td>
<td>0.0092</td>
<td>0.609</td>
<td>0.103</td>
<td>0.776</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAIN DRAIN</td>
<td>0.0001</td>
<td></td>
<td></td>
<td>0.005</td>
<td>0.0001</td>
<td>0.141</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean % Cover 45 57 39 51 56 42 82
Diversity of species 45 49 56 51 40 51 45
Number of sample sites studied 23 49 60 62 60 34 25 313
Mean width water level in meters 6.7 3.6 1.29 0.87 0.8 1.69 2.3
Frequency of maintenance 3 3 3 3 3 3 1

P>0.05 = There is no significant difference
P<0.05 = There is a significant difference

MC = main canal; BC= branch canal; UF = unit feeder; F = feeder; FD = field drain; CD = collector drain; MD = main drain.
These weeds were soon shaded out by more robust marginal weeds such as *Leersia hexandra* and *Commelina* sp. As the weed density increased, the *Leersia* sp. was shaded out in the major channels by *Panicum repens*, *Typha latifolia* and *Echinochloa pyramidalis*. 
Table 4.12 shows the results of the comparison of the percentage cover of the weeds in the different channel types studied in MIS.

The values in bold figures are all less than 0.05 meaning that the difference in vegetation cover in the channels being compared was greater than the difference expected to be caused by chance or by sampling error and that there is cause for that difference, i.e. there was a significant difference in vegetation cover in the two sites of the main canal studied, between the unit feeders and main canals, between the collector drains and main canals and between the main drain and main canals as shown in row two (Table 4.12).

4.14 Effects of environmental factors and weed growth

There were seven different functional types of channel studied in MIS. They had different dimensions and also differed in the water chemistry leading to different environmental conditions experienced by plants. These factors were temperature, flow velocity of water, pH, electrical conductivity, water colour, channel width, depth, substrate and bank slope. Other factors were drying out, flooding, grazing and different methods of weed management, each of which influenced weed growth. The main weed species identified in different types of channels are as shown in Tables 4.1, 4.8 and 4.9. Some of the mean environmental factors and mean vegetation covers of the seven different channel types are shown in Table 4.13.

The main canal was the widest and deepest channel in the scheme, it had the fastest water flow, the lowest electrical
conductivity and the lowest temperature. The field drains were the shallowest with slowest water flow, had the highest temperature, highest electrical conductivity and highest pH. Feeders were the narrowest channels in the scheme (Table 4.13).

4.14.1 Channel width
The highest vegetation cover was recorded in the main drains (82%) followed by branch canals (57%), and the least in the unit feeders (39%) (Table 4.13). The width of the three main channels studied were the main canal, 9.15 m, branch canal, 5.55 m, and main drain, 5.34 m. There was correlation between the width and the vegetation cover in the three major channels i.e. main canal, branch canal and the main drain: the wider the channel, the lower the vegetation cover. When all the seven channel types were considered there was no correlation between the channel width and the mean vegetation cover. Other environmental factors affected the percentage cover.

The narrower the channel the faster the growth rate of the percentage cover with an exception of collector drain and the main drain (Table 4.13). The collector drain was second in the growth rate (0.95%/day) but was wider (3.1 m) than the field drains (2 m) and the unit feeders (2.08 m). The slowest growth rate was recorded in the main canal (0.24%/day) followed by main drain (0.42%/day).

4.14.2 Channel depth
The main canal, branch canal, and main drain were the deepest channels in the MIS (Table 4.13). The mean percentage cover in these three channel types was least in the main canal and most in the main drain hence the deeper the channel the less the percentage cover. The comparison of depth in the irrigation channels and the percentage growth rate of the
Weeds indicates that the deeper the irrigation channel the slower the percentage growth rate, i.e. the main canal was the deepest irrigation channel type (0.9 m deep) and had the slowest vegetation cover growth rate (0.27%/day) and the feeder, the shallowest of the irrigation channels, (0.22 m deep) had the fastest vegetation cover growth rate (0.99%/day) (Table 4.13). This shows that wide deep channels have the slowest vegetation cover growth rate (0.27%/day - 0.64%/day).

The percentage cover of the unit feeders (39%) was lower than that of the collector drains (42%) and the percentage cover growth rate of weeds in the unit feeders was slow (0.82%/day) compared to the rate in the collector drains (0.95%/day). The unit feeders were also deeper (0.37 m) and narrower (2.08 m) than the collector drains (0.30 m deep) and 3.1 m wide (Table 4.13). This shows that depth of a channel is more important in the weed control than its width.

Table 4.13 Mean environmental factors and mean vegetation cover in different channel types in Mwea Irrigation System, Kenya. (Source: Botanical survey. WBT = width at bank top; VGR = vegetation growth rate; BKS = bank slope in degrees; MAXD = maximum water depth; FV = flow velocity; EC = electrical conductivity; TEMP = temperature; VEG = percentage vegetation cover)

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>WBT (m)</th>
<th>VGR (%/day)</th>
<th>BKS (°)</th>
<th>MAXD (m)</th>
<th>FV (m³s⁻¹)</th>
<th>EC (Scm⁻¹)</th>
<th>pH</th>
<th>TEMP (°C)</th>
<th>VEG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel</td>
<td>9.2</td>
<td>0.22</td>
<td>30.0</td>
<td>0.90</td>
<td>0.58</td>
<td>50</td>
<td>8.2</td>
<td>20.2</td>
<td>45</td>
</tr>
<tr>
<td>Branch canal</td>
<td>5.6</td>
<td>0.64</td>
<td>57.1</td>
<td>0.86</td>
<td>0.55</td>
<td>51</td>
<td>8.2</td>
<td>20.8</td>
<td>57</td>
</tr>
<tr>
<td>Unit feeder</td>
<td>2.1</td>
<td>0.88</td>
<td>71.1</td>
<td>0.37</td>
<td>0.36</td>
<td>58</td>
<td>8.5</td>
<td>22.6</td>
<td>39</td>
</tr>
<tr>
<td>Feeder</td>
<td>1.4</td>
<td>0.99</td>
<td>67.3</td>
<td>0.22</td>
<td>0.29</td>
<td>73</td>
<td>8.2</td>
<td>24.1</td>
<td>51</td>
</tr>
<tr>
<td>Field drain</td>
<td>2.0</td>
<td>0.823</td>
<td>66.2</td>
<td>0.13</td>
<td>0.11</td>
<td>532</td>
<td>8.8</td>
<td>28.7</td>
<td>56</td>
</tr>
<tr>
<td>Collector drain</td>
<td>3.1</td>
<td>0.95</td>
<td>67.3</td>
<td>0.30</td>
<td>0.24</td>
<td>120</td>
<td>8.5</td>
<td>25.7</td>
<td>42</td>
</tr>
<tr>
<td>Main drain</td>
<td>5.3</td>
<td>0.42</td>
<td>63.4</td>
<td>0.33</td>
<td>0.26</td>
<td>242</td>
<td>8.5</td>
<td>24</td>
<td>82</td>
</tr>
</tbody>
</table>
4.14.3 **Electrical conductivity**

Water in the main canal had the lowest mean electrical conductivity (50 Scm⁻¹) (Table 4.13) and among irrigation channels feeders recorded the highest (73 Scm⁻¹). Field drains had the highest mean conductivity (532 Scm⁻¹) followed by the main drain (241.5 Scm⁻¹), and the least mean electrical conductivity in the drainage channels was in the collector drains (120 Scm⁻¹). The highest conductivity was recorded in the field drains (950 Scm⁻¹) and the lowest in the main canal (40 Scm⁻¹). The electrical conductivity increased as the water flowed downstream through the irrigation channels.

Electrical conductivity increased from the main canal to the feeders (Figure 4.9), the lowest being recorded in the main canal and the highest between September and January.

Figure 4.9 **Monthly mean electrical conductivity (Scm⁻¹) in irrigation channels (1994-1995)**
The highest electrical conductivity was observed in field drains between September and January (Figure 4.10). In December electrical conductivity was recorded only in the main drain because water in the collector drains and field drains had dried up. In March and April all the field drains had dried and no electrical conductivity was recorded.

Figure 4.10  Monthly mean electrical conductivity (Scm$^{-1}$) in drainage channels (1994-1995)

Di-ammonium phosphate (DAP) fertiliser was added to the rice fields which were top dressed with calcium ammonium nitrate (CAN) during the rice growing period, i.e. September. These fertilisers dissolved in the irrigation water and dissociated into ions, entering the field drains and raising the electrical conductivity. Some ions entered in the feeders with water seeping from the rice fields into the feeders and raised the electrical conductivity in the feeders. Water in the collector drains mixed with excess water from the feeders and this lowered the electrical conductivity in the collector drains. Due to evaporation
of water, the electrical conductivity increased from the collector drain to the main drain.

The mean electrical conductivity for all the drainage channels was 297 Scm⁻¹ and for all the irrigation channels was 57.7 Scm⁻¹.

4.14.4 Bank slope
Unit feeders had the steepest banks (71°) (Table 4.13). Steep banks did not favour the establishment of the weeds and therefore interfered with percentage growth rate. The steep banks had very little vegetation cover particularly where the channel was deep.

4.14.5 pH
The highest mean pH value was recorded in the field drains, pH 8.8. Irrigation channels had mean pH ranging from 8.2 - 8.5, while in the drainage channels, mean pH ranged from 8.5 - 8.8. The drainage channels recorded higher pH values than the irrigation channels (Tables 4.13 and 4.14).

Fig 4.11 shows that there is little variation in pH, over the year I irrigation channels and the highest was recorded between October and January. Fig. 4.12 shows that there was little variation in pH in drainage channels throughout the year.

The field drains were dry in December, March and April and the collector drains in December and therefore no electrical conductivity was recorded in these channels. Field drains had higher electrical conductivity than other drainage channels.
Figure 4.11 Monthly mean pH in irrigation channels (1994-1995)
Figure 4.12 Monthly mean pH in drainage channels (1994-1995)

4.14.6 Temperature
The lowest mean temperature was recorded in the main canal 20.2°C and increase down stream through the irrigation channels, however the highest mean was recorded in the field drains 28.7°C. As the water flowed from field drains, the temperature decreased down the drainage system with lowest mean 24°C recorded in the main drains (Table 4.13).
Figure 4.13. Monthly mean temperature (°C) in irrigation channels (1994-1995)
In Figure 4.13, unit feeders and feeders had higher temperatures than main and branch canals. The highest mean temperature was recorded between October and March and the lowest in July.

In Figure 4.14, the field drains had higher temperatures than other drainage channels. The highest temperature was recorded between October and March. There was no temperature recorded in field drains in March, April, May and in December because the drainage channels were dry. The collector drains were also dry in December (Figure 4.14).

Drainage water had high mean temperature, electrical conductivity, and pH, compared to water in the irrigation channels and the drainage channels had more mean vegetation cover than the irrigation channels (Table 4.14).
Table 4.14 Mean vegetation cover, temperature, pH, and electrical conductivity of all the irrigation and all the drainage channels in Mwea Irrigation System, Kenya. (Source: Botanical survey)

<table>
<thead>
<tr>
<th>CHANNEL TYPE</th>
<th>ELECTRICAL CONDUCTIVITY (S cm⁻¹)</th>
<th>pH</th>
<th>TEMPERATURE IN °C</th>
<th>MEAN % VEGETATION COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation channels</td>
<td>58</td>
<td>8.3</td>
<td>21.9</td>
<td>46</td>
</tr>
<tr>
<td>Drainage channels</td>
<td>297</td>
<td>8.6</td>
<td>26.1</td>
<td>60</td>
</tr>
</tbody>
</table>

4.14.7 Flow velocity

The parts of either an irrigation or a drainage channel with fast flow had lower percentage vegetation cover than the parts with slow flow suggesting that fast water flow reduced weed growth (Table 4.15). Deep channels had faster water flow than shallow channels (Table 4.13).

The main canal had fastest water flow and the slowest flow recorded in irrigation channels was in the feeders. Where the branch canal shows faster flow than main canal was due to measurements taken in different days and weeks. The fastest flow in irrigation channels was recorded in July to November (Figure 4.15).

Drainage channels had slow flow between December and March (Figure 4.16). Field drains were dry in November, December, March and April. The highest flow was between July and October. The main drain had flow throughout the year.
Figure 4.15  Monthly mean water flow velocity (m\(^3\)s\(^{-1}\)) in irrigation channels (1994-1995)
Figure 4.16 Monthly mean water flow velocity (m$^3$ s$^{-1}$) in drainage channels (1994-1995)
After weed management by manual means or by a machine, the species diversity rapidly recovered from zero (Table 4.15) and as the vegetation cover increased, the diversity increased until the vegetation was subjected to stress by either a weed cut, grazing, burning or a dredge.

The most floristically diverse channel was the main canal and a field drain with a maximum of 23 weed species each, followed by a collector drain (maximum: 21 species). The least species diversity was recorded in the main drain and the feeder, 18 species each.

Table 4.15 The relationship between the flow velocity, water depth, vegetation cover and the species diversity for a single channel (Source: Botanical survey - case study collector drain H20CD13)

<table>
<thead>
<tr>
<th>% Vegetation cover</th>
<th>Species diversity</th>
<th>Water depth in meters</th>
<th>Flow velocity ms⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.43</td>
<td>0.33</td>
</tr>
<tr>
<td>100</td>
<td>11</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>65</td>
<td>13</td>
<td>0.20</td>
<td>0.03</td>
</tr>
<tr>
<td>80</td>
<td>13</td>
<td>0.44</td>
<td>0.03</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>0.41</td>
<td>0.14</td>
</tr>
<tr>
<td>20</td>
<td>13</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>40</td>
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<td>100</td>
<td>15</td>
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<td>15</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0.33</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Figure 4.17 Monthly mean vegetation cover (%) in irrigation channels (1994-1995)

Figure 4.18 Monthly mean vegetation cover (%) in drainage channels (1994-1995)
The irrigation channels had more vegetation cover in November to January when irrigation water was not needed. Reduction in vegetation cover indicates periods of weed management and weeds were managed three times a year for each channel (Figure 4.17).

Main drains show more vegetation cover than other drainage channels. Collector drains were weeded to zero percentage cover in August and May. There was more weed cover between September to April.

Drainage channels show more vegetation cover than irrigation channels (Figures 4.17 and 4.18).

4.14.9 Drying out
The floating weeds such as Ottelia exerta, Aponogeton abyssinica, Lemna sp. Ludwigia stolonifera, Marsilea sp. and submerged weeds such as filamentous algae and Najas graminea in the collector drains readily dried out reducing percentage cover with as much as 5% in 31 days, a rate of -0.17 %/day. The reduction was short lived as the seeds of emergent weeds germinated and grew quickly making drying out a less effective means of weed control in the channels. Unit feeders, feeders, field drains and collector drains dried for a period ranging between 2-6 months. During this period the emergent weeds grew quickly as the channels had moist soil and the vegetation cover reached 100% in most channels except in main and branch canals and a few unit feeders. The submerged and free floating weeds constituted very small percentage cover.

4.14.10 Flooding
When branch canals, unit feeders and feeders were flooded due to too much irrigation water being allowed into these channels, the shoots of the emergent weeds such as Leersia
hexandra, and Panicum repens died after being submerged for 21 days. The flooding reduced the growth rate in terms of percentage cover in the channels and washed away the free floating weeds such as Lemna sp. uprooting the weakly rooted weeds along the banks. Flooding was effective in the irrigation channels where the water flow was strong enough to force the weeds to lie completely submerged. In the drainage channels where the weeds were flooded but were not submerged they continued to grow.

4.14.11 Management practices

Table 4.1 summarises weed management practices. The highest percentage cover of vegetation was observed in the main drains because they were not excavated as regularly as in the main and branch canals and as a result were colonised by Typha latifolia, Panicum repens, Leersia hexandra and Cynodon dactylon represented by group 5 (Table 4.8) and in the dendrogram (Figure 4.9).

In the main and branch canals which were dredged regularly i.e. once a year, mean weed percentage cover was from 45% to 57% respectively (Table 4.13). The weeds which established in the main and branch canals are shown in the (Table 4.9) and comprised of Panicum repens, Leersia hexandra, Typha latifolia, Polygonum senegalense, Cyperus dives, Commelina benghalensis, and Ludwigia abyssinica which favoured the channels that were dredged once a year. The manual management in these channels did not interfere with rooting system and had little effect on the weed composition, however it reduced the shading from the tall vegetation and the Leersia hexandra flourished immediately after slashing.

The unit feeders, field drains, collector drains and the feeders were hand desilted and all the roots in the channel beds pulled out leaving vegetation cover at 0% in the
majority of the channels. As a result the weed growth started from the germinating seeds on the mud and the regrowth from the runners of *Leersia hexandra* along the channel banks. Additional weeds were *Cynodon dactylon*, *Ludwigia stolonifera*, *Commelina sp.*, *Eclipta prostrata* *Fluchea bequertti* and *Cyperus sp.* The growth rate of the weeds percentage cover was 0.82%/day - 0.99%/day which was faster than the growth rate in the machine dredged channels 0.29%/day - 0.64 %/day (Table 4.13). *Najas graminea*, *Rotala tenella* and filamentous algae were some of the weeds established in channel beds of newly hand weeded channels with water clear (Table 4.9). The percentage cover of the *Leersia hexandra* was more in the manual managed channels than in the machine weeded channels. The hand weeded channels lacked robust weeds such as *Typha latifolia*, *Cyperus dives* and *Echinochloa pyramidalis* due to farmers uprooting them selectively.

4.14.12 Grazing

The community of MIS grazed their livestock where vegetation was available particularly during the drought. The channels grazed heavily were field drains, collector drains and unit feeders. Main canals and branch canals were grazed after the maize was harvested while feeders were grazed after the rice harvest. The livestock grazed on grasses, sedges and most of the herbs. During the drought they grazed most vegetation to the ground level. Some plant species, such as *Ajuga remota*, *Alternanthera sessilis* and *Cassia sp.* were not grazed on. Overall, grazing reduced vegetation cover. Grazing livestock dragged the weeds with their hooves from one channel to another dispersing weeds in different channels and also dispersed the weeds from the channels to the rice fields and from the rice fields to the channels. The livestock hooves buried the vegetation deep under the ground killing most of it and the pools created by hooves reduced the flow velocity.
Herbivorous fish, snails, grasshoppers, beetles, domestic fowl and wetland birds fed on channel vegetation reducing the vegetation cover. Identification of the species of these fauna involved in the grazing channel vegetation was not carried out.

4.14.13 Water colour

According to field observations, channels with clear water had submerged weeds but the number of such channels was small. Most of the channels had brown or milky water which was opaque and did not allow growth of submerged weeds due to lack of light required for photosynthesis. Main and branch canals had few submerged weeds due to brown opaque water. Some field drains and feeders had clear water in some channels and supported submerged weeds.

The seven channel types in MIS experienced different environmental conditions and different management regimes leading to the establishment of slightly different weed communities in each type of channels.
CHAPTER 5

5. DISCUSSION

5.1 Introduction

The channels of the MIS support a wide diversity of plant species. 134 higher plants species were recorded from 61 sites, the majority being emergent or marginal in nature and indicative of the conditions found in the channels. The number of species recorded is similar to those recorded in channel systems in Europe, e.g. 94 species recorded from Hatfield Chase, England (Wade & Wingfield 1987). In contrast to channel systems in Europe, MIS channels do not support many obligate aquatic species such as submerged and free-floating plants. Only two free-floating species (*Lemna* sp. and *Pistia stratiotes*) and two truly submerged species (*Najas graminea* and *Rotala tenella*) were recorded. Though the concept of aquatic plants and aquatic weed management is useful for the effective management of both submerged and emergent weeds, knowledge of terrestrial weed management is also necessary since some truly terrestrial weeds thrived in these channels especially during the fallow periods. The management of the channels needs to recognise that there are significant periods during which there is no water standing or flowing through the channel though water is available over a longer period in the soil.

5.2 Manual control and hazards to health

Extensive literature on aquatic weeds and the problems of control shows that weeds in the irrigation and drainage channels are a problem all over the world and that the problem is serious especially in the tropics due to the availability of favourable temperatures and water, favouring fast growth rates. While the developed countries are able to acquire the machines needed for the physical weed control or herbicides for chemical control, the developing countries
find it almost impossible to cope with the current inflated prices of such machines which also require foreign currency to purchase them. As a result only large co-operatives or government bodies such as NIB can own such machines and even then the number is usually minimal and inadequate for efficient weed control. Management is therefore mainly manual, slow, inefficient and usually exposes the farmers to the risks of infection by the water-borne diseases. Though there is an argument manual labour is cheap, to the labourer, it is hard labour which sometimes costs them their lives due an infection by the killer diseases and their survival. The availability of improved hand tools for aquatic weed management would be a significant improvement for the manual operators and the tools could be improvised by local manufacturers at an affordable prices and could reduce frequency of infection.

5.3 Weed management
The management of weeds in irrigation and drainage channels at MIS is the responsibility of the NIB and the farmers and is covered in sections 2.9 and 4.3.1 - 4.3.4. The NIB desilt mechanically 90 km of the main canals, branch canals and main drains once a year and the field drains collector drains and unit feeders intermittently. The main canal, branch canals and main drains were slashed once a year by NIB. The unit feeders, collector drains, field drains and the feeders were manually managed by the farmers using pangas and slashers as the tools of management.

The NIB recognised the importance of managing the primary and secondary canals at times of the year when water delivery to the field was crucial, i.e. prior rotavation, transplanting and top-dressing (Table 4.1, Figures 2.6, 2.7, 2.8). Managing drainage channels was also important for draining excess water from the fields and the run-off from the rains
(Figures 2.4, 2.6, 2.9). The drainage systems must be well-maintained if they are not to over-top their banks. Thus the NIB attempted to keep main drains managed but occasionally the drains were left unmanaged for long periods as a result of lack of resources. Thus main drains often had more weed cover than the primary or the secondary canals (Figures 4.1, 4.2, 4.7, 4.17 and 4.18). The weed growth rate in these channels was very fast (0.22%/day-0.99%/day) due to favourable temperatures (20.2oC-28.7oC) (Table 4.13).

Small channels were hand desilted three times a year, but due to their small size, they were quickly overgrown by weeds. The farmers, like NIB, recognised the importance of weeding channels for efficient delivery of irrigation water.

5.4 Methods of weed control.

The major method of weed control in MIS was physical control and both mechanical and manual means were used (see section 4.4). The method is widely used not only in MIS but also in tropical irrigation systems (Mitchell et al. 1990).

5.4.1 Mechanical control.

Excavators were used by the NIB to desilt the channels mainly those >3m wide. The mechanical method used by NIB was faster as longer distance and wider areas and was also more efficient than the manual methods used by farmers because it removed all the plant parts and silt from the channel (section 4.4). When a primary or secondary channel were maintained by an excavator, the channel returned to its primary stage of succession. When the same channel was managed by slashing, the vegetation cover remains almost the same (Annex D: the arrows show management). Thus mechanical excavation is to be encouraged but may not be possible because of the lack of foreign currency required to resource this method. NIB spent Ksh. 1,644,000 a year from the
farmers' sale of rice to resource the method alone and another Ksh. 700,000 to hire the manual labour. Out of five NIB excavators available only four function at any one time due to the mechanical breakdown. Foreign currency was needed to purchase the machines and their spare parts which were not always available. For effective mechanical weed control in MIS, 12 such excavators would be needed to desilt all major drainage and irrigation channels twice a year, however the cost of such machines and their maintenance would be too high for the farmers. The problem of cost and maintenance of such machines are common in developing countries as noted by MAFF (1996). Simple machines could be introduced which may not be very expensive such that the farmers can afford them. Each farmer has 1.6 ha of rice field and the income from the rice is barely enough for the farmers' maintenance and school fees. If such machines were to be bought with the sale of rice, more land per farmer is needed. The Kenya Government probably could develop more irrigated land from the 93% of irrigable land currently undeveloped (section 1.1) and allocate it to some of the farmers such that each farmer may have three to four times the current land allocation. The increase in land allocation would increase income per farmer enabling the farmers to buy machines for channel maintenance.

5.4.2 Manual control.

Manual weed control, although not as fast and as effective as mechanical means, was important as it provided employment for the local people, the farmers were used to manual work and needed no training, the tools used were affordable and needed less foreign currency. Labour was available and allowed the selection of weed species as well as utilisation of harvested weeds for livestock feed and manure. The removal of the weeds from the channels although tedious was necessary to stop the cut weeds from blocking and also decomposing in the channels reducing oxygen concentration as noted by Barrett.
(1978). The tools used were similar to tools applied in other African countries such as Egypt (Robson 1974).

The manual weed control was tedious and the operators became worn out, were generally weak, filthy and wet throughout the weeding period. The farmers were exposed to various waterborne diseases such as malaria, schistosomiasis, and typhoid fever (Table 4.4) partly due to being unprotected in the infected water during weeding of the channels. Some cut weeds escaped and were carried by the water downstream where they blocked culverts and sections of the channels interfering with water flow. The above problems associated with manual control are also common to other parts of the world (Robson 1974). The vegetation growth rate was fast and several cuts were necessary but would have been uneconomical. This led to timing the period of the weed cut to correspond with the period when the water was needed in the scheme, i.e. prior to pre-rotavation flooding, transplanting and top dressing in the irrigation canals and before rainy periods and pre-harvest drying in the drainage channels (Table 4.1).

In view of the above manual maintenance problems, it is important to consider providing the farmers with better tools such as long handled tools capable of reaching the other end of the channel to avoid contact with water. The farmers may be reluctant to use the tools but with education about the importance of the use of such tools, they would come to appreciate and start using them. The NIB should make it mandatory for each farmer to buy a plastic suit capable of covering the entire body leaving only the head. Use of gloves and gum boots when the operators are not entering the water should be encouraged. The NIB field assistance should carry out spot checks on the farmers who may not be dressing properly during the weed management. The rate of manual management may go down but with experience the farmers would get used to new practice and pick up the speed.
Proper toilets should be introduced in the scheme to avoid the water being contaminated with human excrement and hence lower the incidence of schistosomiasis and typhoid fever.

5.4.3 Chemical control

In MIS, chemical control was not applied because the chemicals were too expensive and many farmers were not aware of the chemical control nor how to use them safely. Although the herbicides for aquatic weed control were available, farmers and NIB were not interested in their use as many people were still unemployed and manual weed management provided employment for the local community as well as cheap labour for farmers and NIB.

The literature review has shown that herbicides can have adverse effects on non-targeted organisms and limit water uses. They can be toxic to fish and other animals (Barrett, Murphy and Wade 1990). Mwea people use canal water for domestic purposes and the use of herbicide could contaminate water causing adverse effect on fish, aquatic invertebrates, livestock, people and their crops. Herbicides are reported as cheap, effective and a rapid way of weed control (Gangstad 1978, Holms 1977), and that small patches 2m² could be controlled (Robson 1983). However, if herbicides were to be used in MIS and any other irrigation scheme, only registered herbicides for aquatic weed control should be used as has been recommended in other parts of the world by Spencer-Jones and Wade (1986). The herbicides must be used according to the label and the dosage calculated carefully to avoid water and food contamination (Gangstad 1978).
5.4.4 Other methods of weed management in Mwea Irrigation System

The methods below were not recognised as weed control by the farmers and the NIB although they reduced the channel vegetation drastically.

Biological control

In MIS the grazing of the livestock was a very effective means of biological control and is described in section 4.4.3. In addition to livestock control was exerted by fish, aquatic fowl, snails and invertebrates which grazed on channels' vegetation as observed by other researchers (Crafts and Robbins 1962a, Gupta 1973, 1979, 1987, NAS 1976, Barrett, Murphy and Wade 1990). Farmers benefit from the control organisms by getting milk, meat, eggs, manure and labour. The only form of input in the control was the initial cost of the control organisms such as a cow or a goat and pay a salary for a herdsboy.

During grazing the livestock destroyed the channel banks and encourage soil erosion, however, the problem could be solved by the use of portable fence as noted by Gupta (1979). Biological control was slow especially during the rainy periods when vegetation growth rate was fast and due to the livestock being selective in their feeding habits leaving some weed species undisturbed such as *Typha latifolia*, *Polygonum* sp. and several others especially medicinal plants such as *Ajuga remota* and *Cassia didymobotria* due to availability of wide choice of vegetation. Hence the method was not always effective. Although the method reduced weeds drastically during dry period, it never removed all the weeds as physical control did. The method reduced height of weeds and reduced the frequency of weed cut along the channels. Unlike manual control there was very little energy applied.

Insects such as *Neochetina bruchi* and *Neochetina eichhorniae* have been used to control *Eichhornia crassipes* in South
America (Charudattan 1986) and *Cyrtobagous salviniae* and *Someodes albiguttalis* controlled *E. crassipes* and *Salvinia molesta* (Njuguna 1991) whereas *Neohydronomous affinis* controlled *Pistia stratiotes* (Chikwenhere and Forno 1991). MIS was not invested with the above weeds of international interest but the farmers and NIB need to be aware of them so as to eradicate such weeds as soon as they are identified.

In MIS Chinese grass carp (*Ctenopharyngodon idella*) could be introduced to feed on weeds and provide protein. Snails such as *Pomacea australis* feed more vigorously and on more aquatic weed species than *Marisa cornuarietis*. *Marisa cornuarietis* eat eggs of disease carrying snail and is itself disease free and forms a good food source for human consumption, however, in rice fields it also feeds on rice (Gupta 1979). These two species of snails could reduce weeds drastically and reduce incidence of schistosomiasis. Water fowl were common in MIS and have been used elsewhere in control of aquatic vegetation and also provide meat and eggs for human consumption. This is confirmed by observations made earlier that Kenya is rich in avifauna and out of 1,060 species of Kenyan birds, 225 species are associated with water (Gichuki and Gichuki 1991). Elsewhere biological control has been found to have a high cost benefit ratio and low energy expenditure.

*Leersia hexandra* the most common weed in the scheme was controlled by the tall species such as *Typha latifolia* and *Echinochloa pyramidalis* which shaded *L. hexandra* out. Submerged weeds such as *Rotala tenella* and *Najas graminea* together with floating species such as *Filamentous algae* and *Lemna* sp. were wiped out by dense emergent weeds through competition. The floating and the submerged weeds were not a management problem in the channels but they formed thick mats in the fields which were effectively kept free from the emergent weeds by the farmers.
5.4.5 Environmental Control

Flooding
In MIS flooding drowned the emergent weeds and washed away free floating species as has been observed in other places (Wade 1990). Although the method controlled the weeds both in the rice fields and in the channels, the rivers did not have enough water for irrigation let alone for weed control in the channels.

Drying
Drying out killed submerged weeds in the dry channels, and also in the rice fields. Whilst this was very effective in the rice fields, it was not an important means of weed control in the channels as the troublesome weeds in the MIS channels were mainly the emergent forms, which shaded out the submerged ones, however in the events of effective weed control of the emergent species, the submerged and the floating species could cause serious problems and then could be controlled by drying out of the channels as has been done in other countries such as India, and Europe (Gupta 1979, Barrett Murphy and Wade 1990). Although the management cost would be low, it would interfere with water use for domestic purpose and for the fish and invertebrate life as observed by Wade (1990). Mwea farmers depend heavily on the canal water (Table 4.5) and if the canals are dried they would experience many problems. Shorter periods of alternate flooding and drying could be introduced to control the above weeds but different sections of MIS should be scheduled to receive this treatment at different times to avoid water shortages and to ensure that the farmers and their livestock were not deprived of water for a long time.
Burning

Burning with its advantages and disadvantages is described in section 4.4.1. It is cheaper than any other method of control but it is only applicable during the fallow period after harvest when the weeds and the channels are dry. It kills all living organisms in the channels including disease causing organisms such as fungus. Weed burning could also be used to eliminate poisonous weeds such as *Datura stramonium* as reported elsewhere (Barrett, Murphy and Wade 1990). The method has been successfully used to control ditch bank weeds (Klingman and Ashton 1982, Crafts and Robbins 1962b). At the time when the method was applicable it was also the time when livestock required the vegetation. The NIB could use the method to control *Typha* sp. in the drainage channels as has been done in the Imperial Valley California (Craft and Robbins 1962a).

Channel depth

Channels such as main and branch canals showed that the deeper the channel the lower the vegetation cover. This was also observed in the collector drain and unit feeders (Table 4.13). The rooted vegetation in these channels were restricted to shallow water along the channel margin. The channel bed was also free of submerged weeds due to lack of light for photosynthesis. The literature review showed that at a depth of around 1m or more, the rooted plants are unable to establish readily (Klingman and Ashton 1982) and are restricted to the shallow margins while submerged weeds were restricted to depths where sunlight can reach.

Main and branch canals were the deepest channels in the scheme and were expected to show the least vegetation cover. This, however, was not true in MIS. As Table 4.13 shows the unit feeders and the corrector drains had the lowest mean vegetation cover. Main and branch canals were desilted once a year and unit feeders and collector drains were hand desilted.
three times a year. Slashing in the main and branch canals achieved very little reduction in percentage cover. Large channels should be made deeper for the purpose of management. At the depth of 0.5m, no submerged weeds grew due to the turbidity of water.

Bank slope
The steep bank slopes had reduced vegetation cover as compared to gentle bank slope. The unit feeders, collector drains and feeders had the steepest banks: 71°, 67° and 67° respectively. Unit feeders had the least vegetation cover followed by collector drain then feeders and the most in the small channels was field drain. This indicates that the steeper the slope the less the vegetation cover. The steep slope reduces the surface area on which the vegetation can root and hence shows reduced vegetation cover. According to Klingman and Ashton (1982) steep slopes of 3:1 greatly reduce surface area where weed can grow.

Flow velocity
Fast flow velocity discouraged weed growth by disturbing the root system and the substrate. The water carried away the floating Lemna sp. together with loose soil substrate. According to Barrett Murphy and Wade (1990) the rate of water flow and the type of sediment affect aquatic plants distribution. A section of channel with slow flow typically had more vegetation cover than one with fast flow and required more frequent management than the ones with fast flow. e.g. H20BC55 had slow flow and hence more vegetation cover than H2BC38 and yet they were both branch canals.

5.5 Weed problems in irrigation and drainage channels of Mwea Irrigation System
Weeds in the channels reduced water flow velocity as shown in Table 4.15. Channels with the same water depth showed reduction in flow velocity as the vegetation cover increased.
This aspect was not easy to investigate as the rate of weed growth was fast and the whole channel length was not necessarily cleared at the same time. The volume of water in the channels was regulated by the NIB and sometimes the channel was weed free but due to reduction of water volume the flow velocity did not reflect the increase that was expected.

Cut weeds reduced water flow especially above the culverts where they were trapped. Despite efforts by the farmers and NIB to remove most of the cut weeds, some of the weeds were still carried downstream where they caused problems. Weedy channel margins had more silt than the cleared margins due to weeds encouraging silt deposition as has been observed in other parts by Klingman and Ashton (1982).

More malaria causing mosquitoes and species of aquatic snails of the genera Bulinus and Biomphalaria, transmitters of Schistosoma mansoni and S. haematobium, were observed in the weedy channels than in the weeded channels, as was also observed by Mavuti (1990). The observation explains the high malaria and bilharzia incidence in the MIS (Table 4.4).

Some weeds and propagules were observed floating in irrigation water into the irrigated fields and there is scope for these weeds to compete with the irrigated rice which is supported by the observation made by other workers (Crafts and Robbins 1962c, and Eggington and Robbins 1960).

5.6 Weeds species identified in Mwea Irrigation System

Table 4.11 shows the most significant weed species found in the Thiba system of MIS. It is based on the weed species with the highest frequency and the highest percentage cover in the 61 sites surveyed in MIS and the results of the farmers' questionnaire. Tables 4.6, 4.7, 4.8, and 4.9 do not
tally exactly and Table 4.10 seeks to combine the perceptions of the farmers which includes not just the extent of a particular weed species but the difficulty encountered in controlling it, and also the scientific approach of the extensive botanical survey.

The majority of weed species identified were rare and only very few species were dominant. This is in line with the observation made by Andrews et al. (1974). The most problematic weed species tend to be grasses and sedges, Commelina sp. being an exception. The grass *Leersia hexandra* comes out top of the list. It is very widespread and particularly well adapted anatomically and physiologically to the channel habitat. It is able to live in waterlogged soils as long as there is enough sunlight and can tolerate periods of drought characterising well the necessary attributes for survival. Additionally it has an extensive rhizome system from which it can quickly vegetatively regenerate after channel maintenance.

*Leersia hexandra* although frequent throughout the system, had the highest percentage cover in smaller channels with lower cover values in the larger channels. This was due to the larger channels having more bank growth which was typically tall, shading out species such as *L. hexandra*. Management practices along the banks of the smaller channels prevented tall species establishing.

Most channels of MIS lack any shading due to management practices which eliminate any tall growing plants to prevent their harbouring birds which could be pests feeding on the rice crop. The combination of sunlight light, water availability and high temperatures (minimum 20°C in the main canal to a maximum 29°C in field drains (Tables 4.13 and 4.14) is ideal for species such as *L. hexandra* and enables these plants to achieve dominance over many of the other species.
The other grass species of significance were *Cynodon dactylon*, *Panicum repens* and *Paspalum scrobiculatum* (Table 4.10). All possess rhizomatous stems which sprout immediately after a weed cut (Annex C). Their rhizomes are able to grow in waterlogged soils surviving low oxygen concentrations and tolerating the acidic conditions produced due to plant respiration in the absence of oxygen. They have thin scaly leaves adapted to absorbing oxygen in conditions where it is limited. The rhizome of *L. hexandra* is hollow, i.e. has a large air space which is utilised by the plant during the waterlogged conditions. *Commelina* sp. though not a grass or a sedge, also has underground rhizomes which can survive management events, e.g. cutting. This genus also reproduces vegetatively and tolerates drought on account of its being succulent. *Cyperus rotundus*, in addition to its rhizome system also produces bulbs from which it can rapidly regenerate. Other successful species adapted to waterlogged conditions are *Typha* sp. especially where management is infrequent and *C. dives* and *C. latifolius*. All three species have extensive root systems.

The broad-leaved species such as *Ludwigia stolonifera*, *Marsilea* sp. and *Polygonum* sp. are also capable of vegetative reproduction through their underground rhizomes or runners. *Ludwigia stolonifera* has floating roots which are specially adapted to store air to help keep the plant afloat and overcome periods of low oxygen availability while *Ludwigia abyssinica* has roots which grow above the ground (Annex C).

The species diversity found in a 20 m site did not vary much across the Thiba section though the most species diverse sites were in the main canal and the field drain with maxima of 23 species, while sites in the main drain and feeders had the least species diversity: 18 (section 4.14.7).
Table 4.12 shows that the most floristically diverse channel type was the unit feeder with a total of 56 species followed by feeder and collector drains, 51 species each, and then by branch canal, 49 species, and the main canal and main drain 45 species each. The least floristically diverse channel type was the field drain: 40 species. Further investigation would be needed to explain the variation in the species diversity in the different channels.

Table 4.15 shows variation in species diversity as a result of weed management which indicates that the newly managed channels had fewer species, if any at all, and the unmanaged channels had more weed species. There is also variation in species diversity as shown by TWINSPAN (Table 4.8) in which the most floristically diverse group of channels was group 5. This was made up of three main drains and one field drain. TWINSPAN grouped channels according to the species in the channels reflecting management regime and physical characteristics such as width. Several different channel types were grouped together depending on the time they were managed. The recently managed channels had the lowest species diversity (Tables 4.8 and 4.15).

Most field drains maintained both aquatic and terrestrial conditions in different months of the year. When there was no flooding, most small drains were dry and supported terrestrial plants, whilst in the wetter and irrigated periods they allowed several truly aquatic species i.e. submerged, emergent and floating species.

The main canal had large banks providing a large surface area for the growth of robust weed species. Above the water level the banks provided terrestrial condition which alternated with aquatic condition depending upon the water level, leading to growth of emergent and free-floating as well as floating leaved species. This zone supported transitional
species such as Panicum repens, Cynodon dactylon, Polygonum species, Commelina sp, Indigofera schimperi, Ludwigia abyssinica and Echinochloa pyramidalis. The channel was excavated once a year and the large sized weeds had enough time to become established.

Typha sp. was the most frequent weed species in the main drains due to the lack of frequent management. This species large size shaded out other smaller species decreasing species diversity as a result of competition for light. The channels were silted up for a whole year allowing Typha sp., Echinochloa pyramidalis and Panicum repens to grow. Panicum repens was frequent in collector drains, branch canals, main drains and groups 6 and 8 (Tables 4.8 and 4.9). Cynodon dactylon was common in the field drains, Paspalum scrobiculatum in feeders and unit feeders, while Commelina sp. was evenly distributed (Tables 4.8 and 4.9).

Submerged and floating weeds were infrequent as they were shaded out by emergent weeds. They were identified in early stages of recolonization of channels, where the water was clear for the submerged weeds to receive sunlight and grow and also in the slow water for the floating weeds to establish. In main and branch canals the channels were deep and opaque and no submerged weeds grew due to lack of sunlight. The water in the main canal carried a heavy load of silt from the cultivated slopes of Mt. Kenya. Floating weeds were trapped by marginal emergent weeds along these channels.

5.7 Importance of channel type
Channels were designed to fulfil certain functions, the dimensions of the channels differing with function, for example, primary and secondary channels were typically in excess of 6 m in width. In order to maintain function, each
of the channel types experienced a particular maintenance regime and supported particular plant species and communities as described above (Tables 4.1, 4.8, and 4.9). These aspects are described in detail in sections 4.3.1 to 4.3.7. There were seven different types of channels studied and an example of each is shown in Figures 4.1 to 4.7.

The classification of 61 sites using TWINSPAN identified eight groups of sites with certain characteristics. Examination of these end groups revealed that they make good sense ecologically and support observations made in the field regarding the influence of channel type on the plant assemblages found within them. The eight end groups are summarised in Figure 4.8 and Table 4.8.

Group 1 was small, made up of four recently managed quaternary channels, three field drains and one field feeder (Figure 4.8 and Table 4.8) with a very low percentage cover (< 10%). The clear water and the low vegetation cover allowed growth of the submerged species such as *Najas graminea* and filamentous algae. It was noted that these weeds established rapidly after management due to seed and spore banks in the channel sediment. They are, however, poor competitors and disappear as other vegetation such as emergent *L. hexandra* takes over. Weed management pushed succession backwards. Therefore effective management will eventually cause other problems i.e. allowing more submerged species. The relatively high temperatures 24.1°C-28.7°C (Table 4.13) and high electrical conductivity (210 Scm⁻¹) were favourable to weed growth (Table 4.8). It was one of the end groups with the lowest species diversity i.e. 6 species per site.

Group 2 was made up of predominantly quaternary and tertiary channels, five unit feeders, eight feeders, three field drains and four collector drains a characteristic of which was only a few species per site (Table 4.8).
were managed frequently by hand and most of the species noted were those left behind after weeding. The mean vegetation cover was 43.7%. As in group 1, some sites were of recent management, but weeds were older than in the group 1. The submerged weed species were already shaded out leaving low species diversity as in group 1 (Table 4.8) due to recent management. The indicator species was Commelina sp. also commonly found in terrestrial and aquatic conditions (Figure 4.8) and its autecology is covered (Annex C).

Group 3 also comprised a mix of channels. The mean vegetation cover was 45.5% and there had been a longer period of absence of management than in Groups 1 and 2. An indicator species for this group is Leersia hexandra and other weed species present were bank weeds which grow immediately after the water recedes. These weeds are able to establish after weed management from weed stumps left after cutting and include species such as Cyperus sp., Desmodium sandiviscense and Dyschoreste maghana. These channels were dry for a period of not less than two months and the plants are adapted to live in terrestrial conditions during drought. Group 3 was the largest with thirty four sites (Table 4.8). The group represents the sparse emergent stage and the weeds in these channels indicate a need for management (Figure 1.2). The sites had a low electrical conductivity (48 Scm\(^{-1}\)).

Group 4 comprised six field drains (Table 4.8). The water temperature was high and the water more alkaline than groups 2 and 3. The channels were dry most of the time as they were located at the upper reaches of the field drains and the only form of management was biological weed control through livestock grazing and weed destruction by their hooves. They were silted up and supported semi-aquatic and terrestrial vegetation such as Cynodon dactylon, Acmella caulorhiza, Commelina benghalensis, Cyperus sp. Dyschoreste maghana and Ajuga remota (Table 4.8). The few filamentous algae recorded
in these sites grew in pools of water trapped by the depressions left by livestock as they grazed during the rains. The lack of maintenance was the key distinguishing feature between this group and Group 1. An indicator species for this group, *Fimbristylis* sp. which grows well where management does not disturb its root system. It can grow in mud and does not need standing or flowing water (Annex C). The weeds in this channels group had reached the plagioclimax stage in the vegetation succession in the field drains and the feeders. This is a stage when the management is mandatory. The channels were of little use to the farmers due to silting up and had reached the condition of the abandoned stage (Figure 1.2) and the vegetation succession had reached the terrestrial form. The channels should not be allowed to reach this stage as the water delivery would be interfered with.

Group 5 was characterised by three main drains and one field drain (H6FD15) which was however similar to the main drains in terms of width bank slope and plant community. All of these sites had water most of the time although water level fluctuated. They were managed infrequently, often with as much as two years between maintenance events and consequently had high percentage cover of vegetation with a mean of 67.5% (Figure 4.5, 4.8 and Table 4.8). The most important factor in the group was channel width combined with the lack of management. The high conductivity and high temperatures created suitable conditions for rapid plant growth. The sites lacked species such as *Ageratum conyzoides* and species composition was mainly *Cyperus dives*, *Echinochloa pyramidalis*, *Polygonum senegalense*, *Typha* sp., *Panicum repens* and *Indigofera schimperi*. The group had a high diversity of species (mean; 18 species) (Table 4.8) due to the availability of both semi-aquatic and terrestrial conditions and lack of management. These plant species also inhabited the transitional zone, ecotone, between terrestrial and
aquatic habitat in the primary and secondary channels (Table 4.11). At this stage the channel required desilting if it was to transport water. The autecology of these weeds are covered in Annex C.

Group 6 comprised a mixture of channels: two main canals, one branch canal and one main drain. The main factors in this group were width of channel, the presence of water in the channel throughout the year and its relatively high velocity 0.62 m$^3$ sec$^{-1}$. Weeds in these sites must be able to withstand not only the water velocity but also low temperatures, 22-24°C (Table 4.13) as well as low electrical conductivity (47 Scm$^{-1}$) (Table 4.8). All the sites had low mean vegetation cover: 35.5%. The main drain, drained grassland area and water from the run-off and not rice fields, thus it did not increase the electrical conductivity of the group. These channels were too deep (0.5-1 m) and opaque to allow the growth of submerged vegetation and the flow precluded floating species. The sites were managed infrequently often only once year which allowed the establishment of firmly rooted species such as Cyperus sp. and Trifolium semipilosum on the channel margin.

Group 7 comprised five branch canals, four unit feeders, two main canals and one main drain. These sites, as in Group 6, were channels with water throughout the year and with relatively fast flow (0.55 m$^3$ sec$^{-1}$). The drain acted as a spillway so that when there was excess water in this main channel. All the channels had low conductivity (Table 4.8). The species with the highest constancy were mostly bank vegetation adapted to both aquatic and terrestrial conditions (Annex C). Some species were well rooted and others had underground rhizomes to support them against water current. The channels had low percentage cover during the time of survey (mean vegetation cover was 48% (Table 4.8)). Although these channels contained water most of the time, they lacked
submerged species because of water depth, high turbidity and presence of emergent forms.

Group 8 comprised only three sites: two branch canals and one main drain. The main drain was also a spill way such that during heavy rains the water had low conductivity. At the time of sampling it had received partial management. The three channels were silted along the bank and had water throughout the year. The water velocity was fast and hence supported the vegetation which can resist water current. This sites represented low vegetation cover in main channels which receive weed management: mean 30% (Table 4.8).

A final group of sites which was not identified by the TWINSPAN comprised those ten channels which did not have any vegetation in them at the time of survey due to very recent management.

5.8 Weed ecology in Mwea Irrigation System

In MIS factors affecting weed growth were the physical characteristics of channels such as width, depth, channel gradient, bank slope and substrate. The water factors included flow velocity, electrical conductivity, water colour, water temperature, pH and presence or absence of the water in the channel. Biological factors involved grazing herbivores and human influence by management.

Different channel types in terms of function and design provided different environmental factors. In terms of function, the channels were either irrigation or drainage and accordingly tended to have a different management regime. Although all channels were supposed to receive management three times a year (Table 4.1), not all channels were managed three times and of those which did, some such as main and branch canals received desiltation only once, while others
such as feeders and unit feeders received thorough manual desilting three times a year. Irrigation channels received more thorough management than drainage channels and this tended to interfere with weed growth, hence less vegetation cover in irrigation channels than drainage channels (Table 4.14). Main drains were neglected due to their large size and the lack of dredging equipment. They received management after all other channels were managed. Therefore when considering the other factors human influence in terms of management affected weed growth and it was necessary to compare the channels which received similar types of management.

Wide channels had less vegetation cover than narrow channels as weeds typically began to grow from the channel margins and it took a longer time for these weeds to cover a wide channel than it took to cover a narrow channel. Due to this time factor, wider channels were able to transport irrigation or drainage water for a longer period than narrow channels. Deep channels had less vegetation cover than shallow channels (Tables 4.12 and 4.13) where the channels received similar management regime, i.e. a main canal had less vegetation cover than a branch canal and a main canal was wider and deeper than a branch canal. Consequently, wide deep channels had low vegetation cover, and slower vegetation growth rates than shallow narrow channels (Table 4.13).

Collector drains are wider but shallower than unit feeders, with slower flow and higher temperature than unit feeders and yet the unit feeders had lower vegetation cover than the collector drains which indicates that depth is more important in the control of the weeds than width. This led to well more established rooted weeds in shallow channels than in deep channels. Submerged weeds also grew in shallow channels where they obtained sunlight although for a very
short time due to the developing competition from other plants.

Shallow channels also allowed growth of emergent weeds on the channel beds which were able to trap floating weeds as the emergent weeds reduced water flow velocity. Deep channels had opaque water limiting the growth of submerged weeds hence low percentage vegetation cover as the weeds could not obtain sunlight.

From the above information, depth and width have been shown to discourage weed growth and as such channels should be made wide and deep for the purpose of weed management in an irrigation system. It is also clear that depth is more important in weed management than width and for that purpose the channels can be made deeper and still remain narrow and would continue to transport water with a reduced management frequency.

Water flow stressed the plants and disturbed the roots. Fast flow swept away floating weed species, uprooted weakly rooted weeds and washed the silt down-stream leaving firm banks where weeds found it difficult to stabilise and consequently reduced vegetation cover and weed growth rate across the channel.

In fast flowing channels, water had a short time in contact with the sediment which lead to low dissolved nutrients and hence low electrical conductivity. This explains the lower electrical conductivity in irrigation channels than in drainage channels. Channels with fast flow had low vegetation cover due to weed stress by water current and low nutrients available for the weeds. In drainage channels, water had been almost stagnant in the fields which were also supplied with fertilisers. The water had been in contact with soil nutrients for a long period and dissolved these
nutrients before it drained from the field into the drainage channels. As a result, all the drainage channels had high electrical conductivity compared to irrigation channels.

Higher levels of electrical conductivity influenced fast growth rate in drainage channels than in the irrigation channels. It would not be easy to reduce electrical conductivity in the drainage channels so as to reduce the management frequency but it is necessary to provide wide high banks not less than 1 m wide to avoid excess seepage of nutrients and the much needed water. The drainage water would have less nutrients and consequently less weed growth. Although drainage channels have faster growth rates than the irrigation systems, the management priority should always be towards the irrigation system since the drainage channels do not need to drain water throughout but can be given priority during the heavy rains and also during the pre-harvest drying.

The channels should also be designed with a steeper gradient to increase the flow velocity for the reduction of management frequency and at the same time not too steep to create irrigation problems.

Channels with a long period of drying had more vegetation cover than channels with a short period of drying. Tertiary and quaternary channels with a long period of drying out had more vegetation cover compared to those with flow throughout the year. On the average, the period with the most vegetation cover is the dry fallow period between November to March. Long periods of channel drying encouraged emergent weed growth, although suppressed submerged and free floating weed species, eliminating them through competition.

Temperature was lower in irrigation channels and higher in drainage channels (Table 4.13, Figures 4.13 and 4.14) which
tended to influence fast growth rate in the drainage channels than in irrigation channels. Temperature influenced rate of photosynthesis and respiration. As a result the higher temperatures tended to influence higher vegetation cover (Table 4.14). Narrow deep channels would provide smaller surface area exposed to the sunlight and as a result the channel water would have lower temperature reducing weed growth rate and would still transport water needed.

**Bank gradient**
Sections of channel with steep bank slope had less vegetation cover. Unit feeders had the steepest gradient and their banks had less vegetation cover as weeds found it difficult to produce roots which could reach the channel bed from the bank margin while gently sloping bank were rapidly established by weeds which rooted easily. The banks should be made steep during management to reduce the management frequency.

**Substrate**
After weed management the silt built up and rooted weeds established in the silt substrate. Due to most of the length of the channels being unlined, there was scope for a large density and variety of aquatic and terrestrial weed species to grow in them. The earth channels provided a natural substrate for the rooting of the macrophytes whereas concrete lined channels allowed rooting of only a few plant species which were highly specialised in their rooting system such as *Potamogeton*. At the joints in the concrete lining, or when the lining accumulated some silt, aquatic macrophytes became established. On the other hand, some species of bank weeds sent stolons floating in water along some parts of the concrete lined channels, trap silt with their roots and leaves and combined with the stems of bank weeds which fell in the channel they caused accumulation of enough silt to allow the lined channel to be colonised by other weed species.
which otherwise would not have grown in the channel. Such plants as Commelina sp. Cynodon dactylon, Panicum repens, Enhydra fructuans, Rhyncosia sp. and Cyperus dives were common in such places. However, the problems these plants created was of low magnitude compared to those growing in the earth channels.

Most of the channel substrate was black cotton soils which are characteristic of savannah and are the most fertile soils in the world as observed by Andrews et al. (1974). In view of the above, concrete lined channels would be best for the purpose of weed management but this is too expensive.

Grazing
Grazing was an effective weed management reducing vegetation cover especially in channels along the road. Grazing alone was not enough particularly during the rainy season when vegetation growth was fast. In addition herbivores preferred some weed species and others were not grazed and hence control was not effective for some weed species especially Typha sp. and Cyperus latifolius and Cyperus dives. Other methods need to be incorporated in the management. Invertebrates such as beetles, grasshoppers, caterpillars reduced vegetation growth drastically.

Zonation
Weed zonation in the irrigation and drainage channels showed that the main canal, branch canal had no vegetation in the middle. This was due to the water being turbid due to silt carried by water from heavily cultivated slopes of Mt. Kenya where soil erosion was severe and red soil was carried by water. Therefore the irrigation channels especially during heavy rains had brown water and did not allow submerged weeds to grow and because they were wide and had fast flow, did not allow growth of the emergent weeds such as Panicum repens whose long stolons, sometimes 4 m long grew along the channel.
margins due to being washed away by water current as they tried to grow across the channel.

In small channels (tertiary and quaternary channels) the middle of the channel has less vegetation than the channel margins and the banks. The weeds in the middle were mainly submerged species such as filamentous algae, Rotala tenella and Najas graminea, free floating species e.g. Lemna sp., while floating leaved species included Aponogeton abyssinica, and Ottelia exerta. Field drains and collector drains where flow was slower supported Marsilea sp., and Ludwigia stolonifera. Emergent Leersia hexandra was also observed in these channels as its underground stolon crept easily across the shallow narrow channels.

On the channel margin, Cynodon dactylon, Leersia hexandra, Panicum repens and Paspalum scrobiculatum were the most frequent as they could find substrate for the roots and draw enough water. This region was occasionally flooded during high flow and was sometimes dry during low flow and represented the transitional zone. On the bank top, weeds such as Bothriochloa insculpta and Cynodon dactylon and Commelina sp. were dominant and represented the terrestrial zone (Table 4.11). These could withstand periods of long dry spells to which the weeds were well adapted. In main drains, Typha latifolia was dominant all over the silted channels except on bank top. Typha latifolia and Echinochloa were observed in neglected channels.

**Succession**

Weed management by excavation or manual desilting left the channel mostly with 0% vegetation cover, a condition referred to as new channel condition. The growth of weeds began with submerged species together with floating species. Later the marginal emergent weeds grew from seeds and other propagules such as rhizomes spores, and bulbs. The marginal emergent
vegetation increased in density and changed from sparse marginal emergent to dense emergent (Figure 1.2). At this stage the submerged and floating species were already shaded and eventually wiped out. There was a rapid turnover of species due to the availability of warm water temperatures which were favourable to weed growth.

In narrow shallow channels, the percentage growth rate was rapid and in many sites the submerged floating species were not observed but the emergent species grew from the channel beds from the remains of underground rhizomes and seeds. In a few sites where manual desilting uprooted all weeds in the channel bed, the submerged floating species were observed but only for a short time before they were subdued by emergent weed species. The dominant weed species in small channels was *Leersia hexandra*. This was the climax hydroseral stage in most of the small channels. Table 4.9 shows *Leersia hexandra* is dominant species in all channels except in main canal and main drain where *Panicum repens* is dominant. The weeds adaptation is covered in Annex C.

In main channels, the channel condition after desilting followed a similar cycle to that in small channels, however the species turnover was not as rapid as in small channels because of presence of space and reduced competition for light. The submerged stage was observed in main drains during low flow in the open spaces or after channel dredge and in main canal along the margin. The main canal lacked submerged channel bed weeds because the water was turbid and brown and there was little or no sunlight penetration for photosynthesis. The floating species were along the channel margins protected by the emergent marginal weeds.

In desilted main and branch canal, the earlier species were filamentous algae, *Lemna*, *Leersia hexandra*, *Cyperus* sp., *Acmella caulorhiza* and *Ageratum conyzoides*. These were
succeeded by *L. hexandra*, *Commelina* sp. and *Panicum repens*. These were replaced mainly by *Panicum repens*, *Commelina* sp., *Echinochloa pyramidalis* and *Typha latifolia* as the dominant weed species. *Ludwigia abyssinica*, *Cyperus latifolius* and *Cyperus dives* were common.

At the dense stage, the weeds slowed water flow and encouraged silt deposition and the weed species were more terrestrial in nature and it was mandatory to manage these channels at this time. After desilting, the channel was returned to its normal capacity. The steep channel banks were maintained and the weed growth was interrupted and vegetation succession begun all over from open water with submerged floating weed species (Figure 1.2).

Ecology of weeds in irrigation and drainage channels can be used to reduce the rate of vegetation growth by providing conditions unfavourable to weed growth. Such conditions are steep bank and steep channel bed gradients. Steep banks would discourage emergent weed growth while steep bed gradient would increase flow velocity, discouraging silt deposition and water current would uproot the bank weeds creating stress to the emergent weeds and hence reduction in the weed growth and in management frequency, giving farmers more time to be involved in other activities. Deep narrow channels would also provide unfavourable weed growth and farmers should be advice to deepen their channels during management.

Shading reduced the dominant *Leersia hexandra* and although farmers in MIS eradicate shading to avoid bird pests being harboured, it would be necessary to introduce some tall trees along the banks of the main channels to provide shading as a means of biological and environmental control. Such trees could create a problem during the dredging and to avoid this the trees should be planted on one side of the channel.
Along the small channels low growing vegetation such as *Paspalum scrobiculatum* could be planted, it is easy to manage and does not create much problem in the channels. However, it does not tolerate prolonged drought.

Grazing by invertebrates and livestock should be encouraged. While damage by livestock in the scheme was known, the damage by invertebrate herbivores such as beetles, grasshoppers fish and snails was not clear and it would be necessary to research on those control organisms which appeared to cause significant damage to the weeds such as beetles so that they could be used as natural enemies in the control.

5.9 Environmental Health and Mwea Irrigation System

Farmers suffered from malaria, schistosomiasis, typhoid fever and amoebic dysentery (Table 4.4). Malaria is a water-borne disease caused by a protozoan of *Plasmodium* sp. whose only known transmitter is *Anopheles quadrimaculata* and *A. gambiae*. The disease is common in the tropics due to favourable conditions for mosquitoes. In MIS 100% of the population suffer from malaria. This confirms the earlier findings that there are more malaria cases in the world than any other cases and that it kills 3,000,000 people per year (Gangstad 1978). The mosquitoes were frequent in stagnant water where they laid eggs particularly in the weedy channels. The disease can be controlled by a sharp drop in water level to strand mosquito larvae and kill them. Clearing the channels encourages water flow, washing away the larvae. The drawdown and flooding are also environmental weed control. Fish populations can also be increased to control the mosquito larvae.

81% of MIS farmers suffered from schistosomiasis (Table 4.4) due to the presence of *Schistosoma* (bilharzia) carrying snails mostly found in the small drainage channels such as
field drains and collector drains. This is similar to the observation made earlier that about 200 million people in the world suffer from *Schistosoma haematobium* and *S. mansoni* (Gangstad 1978). The aquatic snails are the intermediate host for the disease. The farmers were in the channels during weed management and they did not wear any protective clothing. Children were exposed to schistosomiasis as they waded in the infected water fishing and transplanting rice.

The incidence of schistosomiasis can be reduced by clearing the channels of weeds before refilling with water. During the reshaping of the channels or designing an irrigation system, an aquatic ecologist, aquatic engineer and a health officer should all be involved to determine bed set up for preventive alternatives (Gangstad 1978). The farmers should be educated on use of protective clothing like gloves and gum boots to avoid contact with infected water. Long handled tools can be introduced and be made available to the farmers.

The farmers drank untreated water from the main and branch canal and also from the Thiba river (Table 4.5). Lack of proper sanitation in the irrigation scheme led to a number of farmers using channel water as means of sewage disposal raising the incidence of typhoid fever. Proper sanitation should be devised to avoid water being contaminated with human excrement and this should be the first priority of any irrigation scheme irrespective of how expensive it could be. Farmers should be encouraged to work as a group and contribute money to finance clean water supply to their villages as the rivers are within the Scheme. Mwea people should have been the first group to have clean piped water.
5.10 Utilisation

Mwea people utilised weeds in various ways (Annex B) and such weeds can be utilised in various other ways as in Gachathi (1989), NAS (1976), Ayensu (1978) and Kareri (1991). This would lead to a reduction of weeds in the channels. The people used weeds as food resources for human consumption and for livestock, as soil additives, as green manure and as compost. *Phragmites australis* (common reed) which grew along Thiba river, was used for house partitioning, fences and for construction of grain stores.

In other parts of Kenya, common reed is used for making sofa sets (Kareri 1991). In Romania, it is used for pulp, to produce printing paper, cellophane, cardboard, alcohol, for insulation and for fertilisers (NAS 1976; ODA 1993). Aquatic weeds like cattails (*Typha* sp.) were used for thatching and as mulching while in some other countries, it has been used for making baskets, marts, chairs, seats, barrels and boats (NAS 1976). The weeds which hardened on drying such as common reed, *Ricinus communis*, *Sesbania sesban* and *Lantana camara* were used as fuel wood for energy production. The weeds growing in channels in other parts of the country can be utilised in biogas production (NAS 1976; Massinga 1991).

In the study area, the weeds were not used for waste water treatment, but in Mombassa Portland Cement Nature Trail, *Pistia stratiotes*, *Eichhornia crassipes*, *Leersia* sp. and mangrove trees were used to remove waste matter and the water was recycled. It has been found that aquatic plants absorb organic and inorganic compounds from water, incorporate them in their tissues and sewage and waste water can be reused for irrigation and industry. The plants concentrate elements 4,000–20,000 times that of the waste water. Some of the plants used are reeds and cattails (NAS 1976).
Some weeds were used as source of herbal medicine, dyes and some for ornamental oils. Some of these plant weeds have been domesticated in some other parts of Kenya. Such plants include castor oil used for firewood and for their seeds which produce useful oil and Amaranthus hybridus used as vegetable throughout the country. The farmers should be educated on various other ways they could utilise these weeds particularly as source of vegetables during the dry period.
CHAPTER 6

6 RECOMMENDATION AND CONCLUSION

6.1 Recommendation

The management regime at Mwea is dictated by the crop cycle particularly by activities such as rotavation, transplanting and top-dressing when the availability of water is paramount and the land drying for the rice harvest when draining is required. While this is important it is also necessary to ensure that the whole length of the channel is managed at one time to avoid some unmanaged sections blocking the water flow. Irrigation channels should receive priority in cases of labour shortage.

The manager of an irrigation scheme should identify the stages of succession and the point at which the individual channels should be maintained. At the emergent weeds abundant/or erect stage (Figure 1.2) the weeds should be managed. This is important so that resources are utilised to their greatest effect. Channels should not be left to deteriorate to a point at which they fail to deliver the necessary irrigation water.

Succession of vegetation in irrigation and drainage channels at Mwea is very rapid due to favourable environmental conditions. Consequently, weed management must be carried out frequently. The successional stages of vegetation are also fast but a weed-cut or desilting operation interferes with the succession and prevents channels from becoming inefficient. The recovery of the successional process after maintenance is faster where ineffective methods of weed control are used and the operator should strive to provide effective control at a reduced frequency such as use of machines.
Special weed control implements such as sawfish, boat sweepers, weed rakes and chain scythes should be introduced to give higher outputs than the equipment as generally used at present. Hand tools should have longer bladed scythes and long handles to reach the other side of the channel. The common implements used in MIS necessitated the operator entering the channel.

The conscious management of weeds in the irrigation and drainage channels in MIS was limited to physical i.e. mechanical and manual control. Grazing livestock, a biological control was prevalent and very successful. It should be considered as a means of managing weeds at Mwea. The grazing should be controlled to prevent damage to the channels and destruction of crops by use of portable fencing. Biological control agents such as beetles, fish and aquatic snails should be researched on and applied where appropriate. Trees should be planted along the main and branch canal, main and branch drains to provide shading and control grasses such as *Leersia hexandra* while in the small channels *L. hexandra* can be reduced by the use growing *Paspalum scrobiculatum* already planted in several parts of MIS but in the process of being eradicated by the farmers due to encroachment. The grass should be protected as it would protect the banks against soil erosion and provide livestock food.

No herbicides have been used at MIS on a regular basis and further research should investigate the use of chemical control. Chemical control might be tried particularly in the drainage channels where water use is minimal. With proper use the chemical control could be more effective than other methods. Large areas can be treated with herbicide with greater ease and can be used in conditions where other control methods are not possible.
Channels design has been shown to be an important factor in discouraging weed growth. Future irrigation schemes should consider the use of wider, deeper channels with steep banks to reduce the rate of weed growth.

Steep banks had less weeds and as such during weeding all banks should be made steep. The channels should also be redesigned to make the very narrow channels wider and deeper as wide deep channels had less weeds. However in an old irrigation scheme such as MIS, increasing channel width may be difficult due to lack of space but depth could be increased. Channel bed gradient could be made steep to increase water velocity in order to reduce weed growth. Environmental manipulation such as construction of steep slopes should be incorporated (Klingman and Ashton 1982; Spencer Jones and Wade 1986).

In MIS the farmers and NIB should aim at integrating all available control methods such as mechanical, chemical, biological and environmental manipulation. Utilisation of the weeds should be incorporated such that when farmers harvest the weeds they ensure the channels are also clean to achieve maximum benefit. The NIB should consider increasing farmers' portions by developing more irrigated land to increase the farmers' income and be able to purchase machinery necessary for effective management and also be protected against infection.

**Problem weed species.**
The most problematic weed at MIS was *Leersia* sp. Complete control of *Leersia* by manual methods is almost impossible and is not desirable since the plant also stabilises the channel banks. This could be harvested for animal feed. The principal weed should be controlled easily by selective hand weeding. The farmers should not aim at complete eradication of *Leersia* and other weeds as they bind soil particles.
together and control soil erosion. *Typha* sp. commonly found in drains can be eradicated through dredging to remove aerial and underground rhizomes or by constant cutting of the aerial shoots to deprive underground roots and rhizomes food resources and hence killing the whole plant.

Although MIS is not infested with problem species such as *Eichhornia crassipes* and *Salvinia molesta*, vigilance is required to prevent their introduction into the scheme.

Farmers have a high rate of schistosomiasis infection. They should receive training on the use of protective clothing and be provided with long-handled tools to reduce the contact with infected water, this would in turn reduce incidence of farmers' infection with diseases and an increase in working ability.

Water-borne diseases are prevalent at MIS and toilets should be provided in the fields to prevent the spread of these diseases via the water in the paddy fields.

The incidence of malaria and schistosomiasis was very high at MIS and further research should evaluate the relationship between channel vegetation and the vectors of this disease. More appropriate hand-tools which reduce the farmers contact with schistosome-bearing water should be introduced.

### 6.2 Conclusion

The present thesis has described the methods of weed management utilised by the NIB and farmers for controlling vegetation in irrigation and drainage channels at Mwea irrigation Scheme. It has also illustrated the problems caused by rapid weed growth arising from favourable environmental conditions.
The characteristics of various species of weed at Mwea have been described. Leersia is most widespread due to its morphological adaptations which makes it difficult to control (Annex C). Some weed species illustrate a preference for certain types of channel i.e. Leersia hexandra preference in all channels types except main canal and main drain, Typha latifolia in main drains and main canals, Cynodon dactylon in the field drains, Ageratum conyzoides and Paspalum scrobiculatum in the feeders, Commelina sp. and Panicum repens, in unit feeders, Panicum repens, Commelina sp. and Echinochloa pyramidalis in the main drains, branch canals and main canal (Table 4.9).

A large number of weed species in MIS channels have been identified and their names given (Annex A) along with the characteristics and methods of control (Annex C) and their specific uses (Annex B). The knowledge of weed names and their characteristics is important in effective management.

The thesis has shown the environmental factors that discourage weed growth are fast water flow, water turbidity, steep bank slope, steep bed gradient, wide deep channels, grazing and shading. All these would decrease vegetation growth and would reduce management frequency. The relationship of the environmental factors and the weed growth are shown in (Annex D). Different channel types provide different environmental factors and that they receive different management programs and support different weeds species and communities as shown (Tables 4.1 and 4.9 and Figures 4.1-4.7).

The management of weeds in irrigation and drainage channels in MIS is a major problem and Ksh. 2,000,000 from the farmers' income is expended on this function by the NIB. The weed management problems are not unique to MIS but are widely experienced all over the world. However, the problems are
severe in the developing countries particularly those in the tropics due to favourable environmental conditions such as suitable temperature.

The techniques for weed management in the irrigation systems are well developed and widely used in the developed countries but the developing countries use mainly manual techniques because of the expensive machines and lack of enough trained personnel to operate them. The developing countries can adopt some of the machines and improve on others to make them suitable for the local use and less expensive.

Chemical control is not used in MIS but it is widely used in the developed countries of Europe and in Australia and the USA. There are various problems associated with chemical control due to misuse as a result of the lack of qualified operators. The literature review in this thesis has shown that if these chemicals are properly used they could be the most effective means of weed control, and could be safe to use even in developing countries.

Biological control is used in MIS and is also widely used all over the world but does not always eradicate weed species, however where used it reduces weeds and hence management frequency. It is cheap, beneficial to humans and environmentally friendly.
I would like to thank all the people who have helped me during the whole period of my study, either materially or through encouragement. I am really grateful to Mr I. Smout of WEDC Loughborough University and Dr. S. Mutiso of Nairobi University for putting me in the project on Management of Weeds In Irrigation and Drainage channels and to Dr. M. Wade of the Geography Department (ICOLE) Loughborough University, who supervised me during my hectic time of study at Loughborough University. Thank you for sparing time out of your busy schedule to guide me in the data processing and the write up; without you I would not have made it. Professor I. Reid, thank you for being director of my research.

I thank WEDC Department for sponsoring me during my field work in Kenya at Mwea Irrigation Scheme. Thank you WWF, Prince Bernhard Scholarship Fund for paying for my registration fee and for my travel, to UK, accommodation and subsistence in Loughborough University. Without your assistance I would not have written my thesis.

Thank you Dr. Ngatia of Nairobi University and Dr. Gichuki of Kenya National Museum, Nairobi for reading my work and giving me guidance. I thank Mrs C. Gichuki of the National Museum for advising me on where to get the Scholarship. Miss Miriam Muita and my niece Lucy Chege I owe it all to your computer knowledge, without which I would not have made any move.

ICOLE staff, thank you for your sympathy; special thanks goes to Liz Traynor, who helped in typing some of the work.
Cath Ferguson, you are a great lady among many I have met. I cannot forget the many hours in MIS with you and lastly you came to save me when I was stuck almost unable to meet the deadline - many thanks.

Last and not least, I wish to thank my family. Your cooperation and encouraging messages kept me working hard. I wish to thank my four children Allan, Julia, Sophia and Robert. Special thanks go to you my husband Mr. W. Thendi particularly for allowing me to go and study in UK; away from home when you could have easily refused given your health situation. Your loving messages of encouragement will never be forgotten. May our Almighty God give you many more years.

To my mum, Sophia K. Hinga I still remember your advice: perseverance and hard work is the gate to success.
REFERENCES


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Ammania auriculata Wild.
Asystasia schimperi T. Anders
Asystasia gagentica (L.) T. Anders.
Basilicum polystachyon (L.) Moench.
(Maschosma polystachyon (L) Benth.)
Bidens pilosa L.

Bothriochloa insculpta (A. Rich) A. Camus
(Dichanthium insculptum (A. Rich) W.D.Clayton)
Cassia didymobotrya Wild.

Centella asiatica (L.) Urb.
Celosia argentea L.
Clitoria ternatea L.
Commelina benghalensi L
Commelina diffusa Burm.
(Commelina nodiflora L.)
Corchorus trilocularis (L.)
Crotalaria chrysocaula Harms.
Cynodon dactylon (L.) Per.
Cynoglossum lanceolatum (Forssk) R. Will.
Cyphostemma orondo L.
Cyperus diffornis L.
Cyperus halpens L.
Cyperus dives Del.

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<td>Polygonum strigosurn R.Br.</td>
<td>Purslane</td>
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<tr>
<td>Polygonum senegalense</td>
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<tr>
<td>Portulaca oleracea L.</td>
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<tr>
<td>Potamogeton swenirfurthii A. Bennett.</td>
<td>Pond weed</td>
</tr>
<tr>
<td>Phytolaca dodecandra L. Herit.</td>
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<tr>
<td>Pychochastys deflexifolia Bak.</td>
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<tr>
<td>Pycreus flavescens (L.) Reichenb.</td>
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<tr>
<td>Rotala tenella(Guill.&amp; Perr) Hiern.</td>
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<tr>
<td>Rottboellia cochinchinesis (Lour) W.D Clayton</td>
<td>Guinea-fowl grass</td>
</tr>
<tr>
<td>Rottboellia exaltata L.f.</td>
<td>Itch grass</td>
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<tr>
<td>Plant Name</td>
<td>Common Name</td>
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<tr>
<td>Ricinus communis L.</td>
<td>Castor oil plant</td>
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<tr>
<td>Rhynchosia malacophylla (Spreng) Boj.</td>
<td>Ihurura (Kikuyu)</td>
</tr>
<tr>
<td>Rhynchosia minima (L.) DC.</td>
<td>Ihurura (Kikuyu)</td>
</tr>
<tr>
<td>Schoenoplectus confusus (N.E.Br.) K. Lye var. confusus</td>
<td>Gitunguru (Kikuyu)</td>
</tr>
<tr>
<td>Sesbania sesban (L.) Merr.</td>
<td>Oda (Luo)</td>
</tr>
<tr>
<td>Senna (Cassia) occidentalis (L.) Link</td>
<td>Ingla-tiang' (Luo)</td>
</tr>
<tr>
<td>Sida tenuicarpa (Vollesen) (Sida cuneifolia Roxb.)</td>
<td>Mwinu (Kikuyu)</td>
</tr>
<tr>
<td>Sida rhombifolia (L.) (Sida ovate L.)</td>
<td>Mwethia (Kikuyu)</td>
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<tr>
<td>Solanum delogoense Dunat.</td>
<td>Sodom apple</td>
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<tr>
<td>Solanum incanum L.</td>
<td>Mvavu (Kiswahili)</td>
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<tr>
<td>Solanum nigrum L.</td>
<td>Inagu (Kikuyu)</td>
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<tr>
<td>Sonchus oleraceus L.</td>
<td>Mahiu (Kikuyu)</td>
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Sorghum arundinaceum (Desv.) Stapf.
(Sorghum bicolor (L.) Moench.
ssp. arundinaceum (Desv.) DC. Wet & Harlan
Sorghum verticiflorum (Steud.) Stapf.
Spermacoce princeae K. Schum.
Sphaeranthus cyathoides L.
Sphaeranthus napierae Ross-Craig
Sporobolus pyramidalis Beauv.
Tagetes minuta L.

Trichodesma zeylanicum (L.) R. Br.

Trifolium burchelianum ser. ssp. johnstonii (Oliv.) Cufod.
Trifolium semipilosum Fres. var. grabrescens Gillett
Trifolium usambalense Taub.
Typha angustifolia L.
subsp. australis (Schumach) & Thonn ) Rohrb
Typha latifolia L. ssp. capensis Rohrb.

Urena lobata L.
Vernonia lasiopus O. Hoffm.

Verbena brasiliensis Vell.
(Verbena bonariensis L.)
Vernonia syringifolia O.Hoffm.
Vigna membranacea A. Rich.
Vigna oblongifolia A. Rich. var. parviflora

Wildegram sorghum
Mexican marigold

Shungs Pwapwa (Kiswahili)

Muhia (Kikuyu)

Muhia wa ngoma (Kikuyu)

Ogolo (Luo)

Oboro (Luo)

Hard heads

Migutu (Kikuyu)

Anyach (Luo)

Angwe (Luo)

Nyanjaga (Luo)

Nyanjagra (Luo)

Muvangi (Kamba)

Bangi (Kikuyu)

Nyesorek (Marakwet)

Nyalak-dehe (Luo)

Mucina-lii (Kikuyu)

Bullrush

Bullrush

Bullrush

Reedmace

Common cattail

Numa (Kikuyu)

Odhong (Luo)

Ndothua (Kikuyu)

Ndothua (Kikuyu)

Othong’ (Luo)

Mrumbu (Kiswahili)

Owich (Luo)

Mucatha (Kikuyu)

Taban’gwa (marakwet)

Tabagawa (marakwet)

Gramineae

Rubiaceae

Compositae

Muhia wa ngoma (Kikuyu)

Ogolo (Luo)

Oboro (Luo)

Gramineae

Rubiaceae

Compositae

Boraginaceae

Papilionaceae

Typhaceae

Malvaceae

Compositae

Verbenaceae

Scrophulariaceae

Papilionaceae
ANNEX B: CURRENT AND POTENTIAL USES OF
HARVESTED WEEDS IN IRRIGATION AND DRAINAGE
CHANNELS

B.1 General uses

In Mwea Irrigation System (MIS) the weeds were used in a number of different ways. The weeds uprooted from the irrigation and drainage channels were put on banks and dried or were buried in the mud in the fields, in both cases contributing to the humus in the soils of the rice fields. Some weeds were harvested from the channels together with weeds on the banks and transported home where they were thrown in cattleshed together with rice straws again to be converted into manure.

Aquatic weeds provided fodder for domestic livestock such as cattle, goats, sheep and donkeys, together with wildlife such as wild geese, crested cranes, rats, fish, grasshoppers and snails. The weeds provided habitat for wildlife such as fish, snails, rats and snakes. They also provided nesting sites for wild aquatic fowl such as crested cranes, ducks and geese. Some farmers harvested the weed and took it home for young calves. They also harvested the weeds for pigs and rabbits (NAS 1976). Weed growing in irrigation and drainage channels protected banks against soil erosion by binding soil particles together. Some farmers used weed for mulching their vegetable gardens.

Some weeds were used to provide, food, vegetables, traditional medicines, lather, and salt. Some provided material for weaving, and for construction of houses. Elderly men and women had used the weeds as vegetables but young people had very poor knowledge of their uses. A number of people had used herbal medicine but had no knowledge of the specific weed species used to make the medicine. Some patients only sought help from medicine men when conventional medicine seemed not to cure their ailments. Various plant parts were used for treatment of different sicknesses. Useful plants like Cassia didymobotria, Ajuga remota and Acmella caulorhiza can be protected for their uses. Specific weed uses are shown (Table B.1).

Table B.1 Specific uses of weeds occurring in irrigation and drainage channels in MIS

Abutilon mauritianum

Mwea: Provides good fibre, browsed by livestock.

Acmella caulorhiza
Kenya: The plant has medicinal value. Crushed plant is applied to a broken limb; flowerheads are used for treatment of toothache and insect repellent; roots treat stomach-ache, constipation, diseases of mouth, gums and throat. (Gachathi, 1989; Lindsay, 1978).

**Ageratum conyzoides**


West Africa: Leaves used to treat pneumonia; used as eye lotion, emetic, purgative, enema; roots treat abdominal pain.

India: It is used for treatment of sleeping sickness, wounds and syphilis. (Ayensu, 1978; Gachathi, 1989).

**Ajuga remota**

Mwea: Medicinal value treat headache, cold, fever malaria.

Kenya: Leaves for treatment of headache, cold, fever, toothache, malaria, pneumonia, stomach-ache, liver problems, skin diseases/dermatitis. The juice of the leaves is applied or the leaves chewed (Gachathi, 1989; Lindsay 1978)

**Alternanthera sessilis**

Mwea: Leaves used for vegetables

Kenya: Leaves used for vegetables.

**Cynodon dactylon**

Mwea: Stabilises banks and protect waterways against soil erosion.


**Commelina benghalensis**

Mwea: Harvested as fodder for pigs, goats and rabbit, browsed by livestock. Used as famine vegetables

Kenya: Stem used in treatment of wounds, burns and sores.

West Africa: Leaves used for treatment of sores, swelling of groins, tumours and burns. Browsed by animals. Food for pigs and rabbits. Used as vegetable during shortage of green vegetables (Gachathi, 1989).

**Commelina diffusa**

Mwea: Browsed by livestock. Harvested as fodder for pigs and rabbits, used as vegetables during famine. Antiseptic
properties. Leaves treat sores, swelling of groins, tumours, burns, itches, and boils.

India: Famine vegetables and as fodder (also in Malaysia and Africa. (Ayensu 1978; Gachathi, 1989; Holms et al. 1977).

\textit{Cyperus articulata}

Mwea: Provided humus, browsed by livestock, dried nuts used as beads for ornamental purposes. Used for medicinal value to treat stomach disorders in infants and hence planted near homesteads (Gachathi 1989).

\textit{Cyperus dives}

Mwea: Provided thatching material, mulch, fodder and manure.

\textit{Cyperus esculentus}

Mwea: Browsed by livestock

Kenya: Bulbs used as an ornament for making necklaces.

South and central Europe: Grown commercially for its edible tubers (Tiger nuts) (Gachathi, 1989).

Zimbabwe: New tubers chewed raw or cooked as vegetables. Roasted ground tuber are used as coffee substitute. Source of potash for softening and favouring green leaves.

\textit{Cyperus rotundus}

Mwea: Browsed by livestock. Bulbs used as ornaments and for medicinal purposes.

Kenya: Bulbs used as ornaments.


\textit{Cyperus latifolia}

Mwea: Browsed by livestock, used for thatching, mulching, ashes used for softening vegetables and for compost manure.

\textit{Echinochloa colona}

Mwea: Provided fodder for livestock. Principal weed of rice world wide. Grazed by cattle. (Cultivated in tropical Asia for seeds which are ground and made into flour).

Zimbabwe: Seed collected and ground into flour (ODA 1994)

\textit{Echinochloa pyramidalis}

Mwea: Grazed by livestock. Stems used as the base of the floor of granary and to make traditional beds.
Kenya: Leaves browsed by cattle, stems used for weaving the baskets used for picking tea. Stems woven for racks and to form base in raised grain stores. Used in making traditional beds (Gachathi, 1989).

*Leersia hexandra*

*Mwea:* Grazed by livestock, harvested for fodder from channels. Eaten by domestic ducks. Used for cleaning calabashes.

Valued as important forage grass in several regions of the world. Has high crude protein and low fibre content (Holms et al. 1977). World wide fodder for horses.

*Ludwigia abyssinica*

*Mwea:* Eaten by domestic ducks.

*Ludwigia stolonifera*

*Mwea:* Buried to provide manure in rice fields. Provides shelter and food for fish. Provides food for ducks.

*Panicum repens*

*Mwea:* Provided fodder for livestock.

*Paspalum scrobiculatum*


*Solanum incanum*

*Mwea:* Medicinal value and browsed by livestock.

Kenya: Juice from fruits and roots is a remedy for abdominal pains. Yellow fruit used for treatment of cold in sheep. Roots used for constipation; fruits produce lather with water (Gachathi 1989). Fruits bitter, inedible, poisonous. Unripe fruits kill rabbits. Browsed by livestock. Non-toxic to sheep. Hottentots and Bushmen use fruit juice to make part of arrow poison.

Nigeria: Root regarded as poison. Treatment of pneumonia.

Lesotho: Treats toothache, sore throat, removes tumours.

Africa: Treats ringworm and itches.

Malaysia: Fruits eaten half ripe in curries; pulped roots pressed in sores. Fruit tonic is purgative.

Java: Taken as diuretic (Watt 1962).

*Sphaeranthus suaveolens*
Mwea: Flower head used for treatment of after birth pains. Flower is fragrant. (Gachathi, 1989)

*Sonchus oleraceus*

Mwea: Good feed for rabbits.

Kenya: Used as vegetable. Feed for rabbits, goats, and sheep (Gachathi, 1989).

Europe: Young shoots sometimes used in salads. Plant may be burnt for salts substitute (Drummond 1984, & Tredgold 1986, both cited by ODA 1994).

*Typha latifolia*

Dry spike produce masses of hair like stuff used to stuff pillows and mattresses. The dry spikes can be dipped in different colours and used for ornamental purposes. Used for mulch. Provides habitat for large and small wildlife as well as nesting site for aquatic fowl and other birds. Leaves used for weaving baskets, chairs and boats, rhizome.

Used as famine food, young stems are eaten as salad or as green vegetables and pollen grain is edible. It is a source of pulp for paper making used in mat making and building roof tiles (NAS 1976).
ANNEX C: AUTECOLOGY OF WEEDS FROM MWEA IRRIGATION SCHEME

Acmella caulorhiza
COMPOSITAE

Habit
Annual, more or less pubescent herb. Creeping at the base or ascending a few centimetres to 50 cm high (Ivens 1990). Leaves more or less ovate, rounded or obtuse at the apex, truncate to acute at the based, 2.5 cm to 5 cm long, 1.25 - 2.5 cm broad. The margin subcartilaginous and setulose, flower heads yellow. 6 mm - 8 mm long, solitary on slender peduncles. Achene black with a line of hairs up to each side and two short slender bristles at the apex (Andrews 1956).

Habitat
In swamps, edges of rivers and ponds and irrigation ditches. Tolerates flooding.

Distribution

Control
Slashing, and uprooting by hand pulling.

Reproduction
Sexually. The seeds fall where the plants grow but are pushed by strong water current to other parts. Grazing mammals and birds carry the seeds on their legs and they drop them in another place away from the parent. Seeds germinate easily.

A sexual reproduction
The creeping stem roots at the nodes giving rise to vertical shoots. The shoot or creeping shoot when disconnected from the parent plant and landing on a suitable environment continues to branch and grow to form a new colony. The shoots are also dispersed by water current, and grazing mammals drag long shoots of the plant from one place to another.

Ageratum conyzoides
COMPOSITAE

Habitat
An erect, unbranched annual herb. 30-60 cm high, stem pubescent. Leaves crenate, ovate or ovate-rhomboid, obtuse or subacute at the apex. Broadly cuneate to almost truncate at the base, 45-80 cm long, 2.5-3.75 cm broad. Setose-pubescent on the nerves beneath (Andrews 1956). Flowerhead bluish-purple or whitish, small, abundant in terminal corymbs, fruit, achene, black when dry, angular glabrous or nearly so. Fruit
an achene, slender, lanceolate, 5-angled black with brown to white base about 1.5 mm long with pappus of 5 white awns (Moody 1981).

**Habitat**
The plant grows in moist soil along the banks of rivers and irrigation and drainage channels. It is found growing in the places shaded by other plants.

**Distribution**
The weed grows in many parts of Central Province, Kenya. It was identified in Mwea Irrigation Scheme and Nairobi in Kenya. It is found in Southern Africa in Transvaal, Natal, Cape, Swaziland and Botswana. (Arnold and de Wet 1994).

**Control**
It is controlled by uprooting and slashing.

**Reproduction**
The plant reproduces sexually by seeds which germinate and give rise to young seedlings.

**Dispersal**
The tiny achenes are light and easily dispersed by water. It can also stick on the feet of herbivores and be dispersed. Birds are also a possible dispersal agent. The achene can be carried by the wind for short distances. The seeds can stick on a labourer’s feet during weed management and get dispersed.

*Alternanthera sessilis*
**AMARANTHACEAE**

**Habit**
The stem creeps over the ground, rooting at the nodes and giving rise to erect shoots which reach 50 cm high (De Thabrew and De Thabrew, 1983). The stem roots on lower parts of the plant. The leaves are opposite lanceolate, 5 cm long, green with a prominent midrib (De Thabrew and De Thabrew, 1983; Hall et al. 1975). The flowers are whitish, 2 mm long, clustered on axillary inflorescence. Fruit - small, flattened, ovate, incandescent, bladder, seed - brown, round (Moody, 1981).

**Habitat**
Found covering muddy sheltered lake shores and in smaller quantities among grasses. In MIS it is found together with *Ludwigia stolonifera* in slow flowing drains and at the edge of canals, growing on mud and on the surface of water, rooting at the nodes.

**Distribution**
Mwea Irrigation Scheme, Nairobi, Kenya; Lake Volta in Ghana and Sri Lanka.

**Reproduction**
Reproduces by seed and vegetatively by a creeping stem which gives rise to roots and shoots at the nodes.
Control
Uprooting, cutting and drying.

Dispersal
Seeds are dispersed by water. Stem fragments are dispersed by grazing animals carrying stems on their feet. Fragments of the stem float in the water to other places.

Ammania auriculata

Habit
The plant has lanceolate clasping leaves. One or two flowers in the axils. Erect annual herb, stem square in cross-section (Andrews 1956). Produces orange red fruits; leaves are linear. The roots become swollen and spongy at the base where they harbour worms.

Habitat
It grows on lake margins, marshes in paddy fields and canal margins.

Reproduction
The plant reproduces sexually through seed formation. The seeds are shed in water where they remain viable and germinate while still under water.

Control
Uprooting the weed before seeds are formed; by slashing.

Distribution

Aponogeton abyssinicus

Habit
An annual fresh water herb with small tuberous rhizome rooting in the mud. Simple leaves with floating lamina attached to a long spongy petiole, 50 cm long, variable in shape and size, 16 cm long x 5 cm wide, more or less parallel sides with blunt tip, wide central vein. Flower spikes branched to form two horn-like prongs, purple coloured, stamens 6, ovaries 3, petals 2, and hypogynous ovary. The inflorescence sticks above the water surface. The two horn-like prongs are 6 cm long by 1 cm wide.

Habitat
Aquatic in slow moving water, in ponds, shallow streams and irrigation and drainage channels. In marshy habitat. In Mwea Irrigation Scheme it grows in rice paddy fields, in slow flowing channels mainly tertiary and quaternary channels.

Distribution
The genus is mainly restricted in East Africa (Ivens 1989). It grows in Mwea Irrigation Scheme, in shallow channels and in drains with slow flowing water. Found in Southern Africa in Transvaal, Cape, Namibia and Botswana (Arnold and de Wet 1994); Sudan (Andrews 1956).

Reproduction
It reproduces both sexual and asexually. The plant produce seeds which germinate in water. In asexual reproduction, the underground rhizome splits to give rise to new plants.

Dispersal
The seeds are dispersed by water.

Control
Uprooting and drying in the sun.

Asystasia gigantica
ACANTHACEAE

Habit
It is an erect annual herb, 60-90 or 180 cm high. Stem angled usually hispid. Leaves oblongate, acute at the apex, tapering very gradually to the base. 7.5 cm - 35 cm long, 1.25 - 3.1 cm broad. Sparingly hispid on both surfaces. Flowers are blue or purple. 2.5 cm - 3.1 cm long in a dense axillary clusters with usually 6 strong spines in each whole and many lanceolate or linear bracts. Capsule about 8 mm long linear oblong 4-8 seeds.

Habitat
The plant grows in wet places, along banks of rivers and along irrigation channels banks.

Distribution
It is found in Mwea Irrigation Scheme in Kenya, in central and southern Sudan (Andrews 1956), Southern Africa (Arnold and de Wet 1994).

Control
In MIS it is controlled by slashing and uprooting.

Reproduction and dispersal
Seeds are released from the capsule by splitting (self dispersal). They germinate and give rise to new plants. Animals can accidentally disperse the seeds with their hooves.

Colocasia esculentus
ARACEAE

Habit
Exotic herb with tuberous rhizomes, has thick succulent stems, usually 0.5-1.2 m tall but occasionally reaches a height of 2 m under favourable conditions. Its large stiff leaves are alternate 40-90 cm long, thick in texture, ovate with cordate base and always peltate. The petiole is spongy and long.
rounded at the tip where it joins the leaf blade but form
open sheath round the stem at the base. The flowers are rare
but when they occur the inflorescence is shorter than petioles
with the staminate flowers occupying the upper three quarters
and pistillate flowers the lower quarter section of a short
cylindrical spadix. The pale yellow spathe is ovate-
lanceolate shaped usually with enrolling margins. The fruit
of elephant ear is an oblong berry containing numerous viable
seeds.

Habitat
It grows well at low and high altitudes, in swamps, marshes,
muddy shallow water areas. Optimum growth occurs in hot,
humid areas. This large shore plant grows in riparian areas
of reservoirs and along the river margins.

Reproduction
Reproduction is both sexually and asexually. In sexual
reproduction the seeds germinate to give rise to small plants
which establish themselves and continue to reproduce
vegetatively by producing spikelets from axillary buds along
the runners. In asexual reproduction, the stem produces
horizontal runners which bud as they grow giving rice to new
shoots from their axilarly buds.

Dispersal
The fragment of runners with buds when disconnected
accidentally by rodents, herbivores or broken by water
current, float in the water and are transported to other
aquatic habitats. They are also dispersed by animals which
carry tubers with their hooves to other places. Man disperses
the plant by cutting suckers and planting them as food crop
both for its leaves and succulent tuber and grows them as
ornaments.

Distribution
The plant is distributed throughout the tropics, in MIS and
in all cultivated marshy areas of Nairobi and central Kenya,
and along abandoned swamp habitats. It is also found in
Pacific and Asian countries.

Control
It is controlled by cutting and uprooting the Runners and the
underground stem. The stems and runners do not die quickly
and hence very difficult to eradicate.

Commelina benghalensis
COMMELINACEAE

Habit
The species has succulent stems and leaves. The stem creeps
on the ground surface and roots at the nodes. The leaves of
alternate, sheathing, with sparsely hairy stem. The stem is
15-40 cm long and branches as it creeps. The leaves are
ovate or elliptic 3-7 cm long and 1-2.5 cm wide, where the
base narrows into a short petiole. The bracts subtend the
flower, spathe are funnel shaped about 1.5 cm long and
flowers are blue. The two anterior ovaries are celled with two ovules each. posterior ovary is also celled and has one ovule. The fruits are capsules which open when mature by dehiscent. The seeds ribbed, rough and grey brown. The underground rhizomes produce subterranean flowers and seeds. (Ivens 1989; Andrews 1956; Moody 1981).

Habitat
Two species Commelina diffusa and Commelina benghalensis were identified in MIS in the irrigation and drainage channels. They are both terrestrial and semi-aquatic. They grow at edges of rivers, lakes, ponds and irrigation ditches. They are also common on farms. The stems creep over mud and on the surface of water and sometimes it creeps across the channel.

Reproduction
Commelina spp. reproduce both vegetatively by fragmentation and sexually by seeds. The stems display xerophytic characteristics and do not dry quickly during wet season. The plant produces axillary buds which grow to new shoots producing new colonies. Subterranean stem produces subterranean flowers and seeds.

Control
Due to its mode of reproduction it is a problem to control. It is mainly controlled by cutting, uprooting and drying. In paddy rice it is by uprooting and burying the plant in mud. It is grazed by livestock. In chemical control, 2, 4-D has been effective only on small seedlings. Glyphosate kills older plants (Ivens 1989).

Distribution
It is widely distributed in Nairobi, MIS Central Province in Kenya, central and south Africa and Sudan (Andrews 1956); Southern Africa, Transvaal, Natal, Cape, Swaziland, Botswana (Arnold and de Wet 1994).

Dispersal
The plant propagules are dispersed by water, animals and man. The pieces of the plants which are cut during weed management float in water and they are deposited in other habitats. Animals drag large masses of weed with their feet to new habitats as they graze. In terrestrial habitat, run-off during heavy rains disperse the vegetative pieces of the plants and the seeds to new sites.

Commelina diffusa
COMMELINACEAE

Habit
It is an annual or perennial herb, sparsely hairy, with a creeping stem that roots at the node. The stem is 30-60 cm long, the leaves are lanceolate 4-6 cm long, 1-2 cm wide, alternate sessile, acute at the apex. (Andrews 1956, Holms et al. 1976). The bracts subtend flowers, the spathe broad, rounded or heart shaped at the base. The blue flowers, have fertile stamens. The fruit a capsule, 3 celled and with five
seeded. Seeds are reticulate, ribbed or ridged (Holms et al., 1976).

Habitat
The plant grows well in moist places in tropics and subtropics. It is subaquatic, growing along river banks, irrigation ditches and ponds. It can withstand flooding and waterlogged conditions. In MIS it is one of the principle weeds in the channels. The stems form mat on moist soil creep on the water surface.

Reproduction
The plant reproduces vegetatively by fragmentation and sexually by seed production. The seeds germinate in mud or moist soil to give rise to the seedlings which grow quickly and establishes themselves to form a whole colony by vegetative reproduction. A small piece of the stem with a few nodes reproduces vegetatively to give rise to a whole colony of the plant.

Distribution
The plant grows in the tropics and semitropics, some parts of Sudan (Andrews 1956). It grows in Nairobi, MIS, in central province, and many other parts of Kenya,. Some parts of Sudan and southern Africa (Arnold and de Wet 1994).

Control
The plant is difficult to control due to its habit of asexual reproduction. When cut it takes long to dry and some fragments survive to give rise to different colonies.

Herbicides control.
2,4-D Is effective only on small seedlings, paraquat is effective at early stages, glyphosate kill even older plants (Ivens 1989).

Dispersal
The plant is dispersed by animals which carry fragments of the plants on their legs to new habitats. The fragments and seeds are dragged by water and seeds left along the bank of channel or river, the fragments can float for longer distances before they are trapped and left on mud where they produce new plant colonies by vegetative reproduction.

Cynodon dactylon
GRAMINEAE

Habit
It is long prostrate fine strong prostrate, fine leaved perennial grass with strong stolon, scaly rhizome, and form dense turf. The grass roots readily at nodes, culms erect or ascending 5 - 45 cm, wiry, smooth. Leaf sheaths 15 mm long but shorter than internode, smooth ligules with conspicuous white hair, laminar linear acute at the apex, 2 - 16 cm long; and 3 - 5 mm wide. Smooth or hairy on the upper surface (Holms et al 1976; Andrews, 1956). Inflorescence 2-6,
spikes light green or purple and occur together. Fruit: a caryopsis, flattened elliptical, red brown (Moody 1981).

Habitat
The plant is a terrestrial, tolerate flooding and drought. It grows in the irrigation and drainage channels, produce long stolons which float in water along canals. The grass also grows in grows on acidic or alkaline soils.

Reproduction
It reproduces vegetatively by producing young shoots at the nodes. The young shoot produces several tillers or rhizomes from axillary bud.

Control
The weed is controlled mainly by cutting. In Mwea irrigation Scheme It was Complete eradication can be achieved by uprooting all the rhizomes and drying them in the sun.

Distribution
The plant is widely distributed in tropics It has been identified in MIS and drainage canals, Nairobi central Kenya and. South and South Eastern Asia (Moody 1981). Useful as pasture grass and for control of soil erosion.

Dispersal
The rhizomes and runners are dispersed by water and herbivorous animals which carry fragments on their legs and deposit them elsewhere as they graze. Seeds grow to new plants. It is also dispersed by man.

Cyperus dives

Habit
A perennial herb, tufted and culms solid, 3 angled 90-120 cm high, 3-6 bracts. Leaves simple, alternate basal tufts, flowers in small solid spikes.

Habitat
It found growing in damp marshy, waterlogged habitats, edge of lakes, marshy areas, banks of canals and drainage channels of the irrigation systems, and in the silted drain.

Reproduction
The plant reproduces asexual by vegetative reproduction where new shoots develop from short underground rhizomes and sexually through seed production. The seeds are tiny and germinate to give rise to other plants.

Distribution
In Kenya, it is found in marshy habitats in central province, in irrigation and drainage systems in MIS, and in Ahero and Kano irrigation Schemes. It is also found in Sudan (Andrews 1956) and southern Africa, in Botswana (Arnold and de Wet 1994).

Control
It is controlled by cutting at the base of the stems next to the root and uprooting and drying dredging. Dredging is a more efficient method of control as it uproots the whole plant.

*Cyperus rotundus*
**CYPERACEAE**

Habit
It is a perennial herb with extensive slender rhizome, white when young and brown when old. Axillary buds on rhizomes give rise to underground tubers at intervals of 5-25 cm, forming tuber chains, irregular or nearly rounded 2.5 cm. Culms erect simple smooth, triangular 10-60 cm high, longer than basal leaves. Leaves glass-like, linear, acute, 5 cm long, 8 mm wide. Smooth, shiny, dark green, grooved on upper surface. Tubular membranous sheath. Inflorescence loose umbel terminal on stem apex; subtended by 2 or 4 leaflike bracts, 3-9 slender spreading three sided peduncles of unequal length (Andrews 1956, Holms et al. 1976). Seed, an achene, ovate or oblong ovate 1.5 m long, 3-angled black when ripe (Moody 1981).

Habitat
It is found in swamps, marshy areas, edge of rivers, lakes, ponds and irrigation channels.

Reproduction
Reproduces both sexually and asexually. It produces large number of seeds which matures and fall on the ground. The seeds germinate on the moist ground giving rise to a young plant which matures and start reproducing asexually by producing runners and bulbs which give rise to aerial shoots. They produce large number of bulbs and runners which reproduces very fast.

Distribution
The distribution of this plant is limited by cold temperatures. It grows in every type of soil, humidity, moisture, pH, survive high temperatures, does not tolerate shading, and grows well on banks of irrigation and drainage channels, in marshy areas, rice paddies, in Mwea irrigation scheme and along some parts of flood plains of River Tana and in Nairobi. It is also found in southern Africa (Arnold and de Wet 1994).

Control
It is controlled by digging the plant and drying the bulbs and the runners in the sun.

Dispersal
The bulbs, runners and seeds are dispersed by water and animals. Runners are carried for a long distance by water before they are left stuck on mud where they begin a new colony. Seeds are small and are carried by water current before they settle. The small seedlings can stick on mud of
grazing animals and birds and can be dispersed to various habitats.

_Echinochloa colona_  GRAMINEAE

Habit
It is a small tufted annual herb up to 5 cm high or descending culm, which branches at lower parts, soft glabrous and smooth. Ligules absent, laminar linear, tapering to slender acute point 8-30 cm long, 4 mm - 6 mm wide, waxy and powdery. Panicles are straight, spikes greenish or tinged with purple (Andrews 1956). Fruit, a caryopsis 1.3 - 2 mm long (Moody 1981).

Habitat
The plant grows in an aquatic habitat mostly in rice paddy in India, and in Mwea Irrigation Scheme Kenya.

Reproduction
It reproduces by seed and vegetatively by budding from the base.

Distribution
There are 30 species of the genus _Echinochloa_ and 20 of them are found in Africa (Thompson 1985) in MIS where _E. colunum_ and _E. pyramidalis_ were found. It is also found in southern Africa (Arnold and de Wet 1994).

Control
The weed is controlled by uprooting and cutting.

Dispersal
Seeds are dispersed by herbivores, birds and water. The water can transport seeds for a short distance before they settle on mud where they grow and give rise to aerial shoots. Herbivores feed on the grass and will carry some of the seeds on their hooves from one area to another. Birds disperse some seeds as they fly, feeding on the grains and carry some on their legs.

_Echinochloa pyramidalis_  GRAMINEAE

Habitat
Perennial reed-like herb up to 4.5 m high. Culms ascending often long prostrate or floating and rooting at the base. 3.6 m - 7.2 m high, up to 1.25 cm in diameter. Many noded simple leaf-sheathed all along the internode. Glabrous sheaths, tight ligules fringed by mostly long stiff hairs. Leaves alternate, laminar linear tapering to a fine point. Panicles erect or nodding linear, oblong, dense 15 to 30 cm long. Spikelets greenish or variegated with purple, sometimes almost blackish purple. Ovate to acute.

Habitat

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In mud and flooded habitats along the river margins and edges of lakes and irrigation canals and drainage ditches.

Distribution

Reproduction
Vegetatively from the rhizome. Fragmentation - the pieces of stem will give rise to a colony of Echinochloa pyramidalis from axillary buds. Sexual - by seed dispersed in various places.

Dispersal
By animals which carry small seeds stuck on their feet to other habitats. The pieces of stem and the shoots are dispersed by water downstream. Seeds are also carried by strong water current from one place to another.

Control
By cutting near the roots or by uprooting and removing the shoot and all the roots and their suckers.

Eclipta prostrata
COMPOSITAE

Habit
Erect or decumbent. Scabrous herb covered with oppressed hairs, 60 or more centimetres high, leaves distantly serrated, lanceolate or narrowly ovate-lanceolate. Subacute or the apex narrowed at the base. Flower heads white, compound, about 6 mm in diameter. Axillary and terminal on slender peduncles up to 3.1 cm long. Achenes 3 mm long dentate at the apex, finely tuberculate pappus, crushed leaves or stems turn dark (Andrews 1956).

Habitat
At the edge of water mainly along the banks of irrigation and drainage channels. In moist places and marshy areas. Mwea Irrigation Scheme in central Kenya, Equatorial region, Sudan (Andrews 1996).

Control
Uprooting, slashing.

Reproduction
By seed. The seeds are heavy and germinate to give rise to seedlings. When a stem has rooted at the node and disconnected it can grow at another place and reproduce asexually.

Dispersal
Is by water current and animals. The fruit can float in water and be transported to other areas.
**Enhydra fluctuans**

**COMPOSITAE**

**Habit**
It is a perennial swamp herb, stem elongated, rooting at the lower end, tubular stem, grows creeping on mud and on water surface. Leaves sessile, entire or distantly serrated, linear or linear lanceolate, 6.9 cm long, finely puberulous and minutely glandular beneath. Flower heads white or yellowish white, sessile, 0.6 - 1.25 cm in diameter. Very few axillary involucral bracts 4, leafy opposed in pairs, fruit, achene oblong, pappus absent.

**Habitat**
It grows well swamps, water edges, edge of lake and irrigation and drainage channels.

**Reproduction**
It reproduces sexually by seeds. The seeds germinate in mud and grow giving rise to a new plant. The older shoots reproduce vegetative giving rise to new shoots from axillary buds.

**Distribution**
The plant is found in Mwea Irrigation Scheme, Kenya and in southern Sudan (Andrews 1956).

**Control**
It is controlled by slashing, and uprooting.

**Dispersal**
The seeds can be washed by water current to other parts. The grazing mammals also dislodge some plant shoots and drag them to other parts, water carries some of these fragments to other places, where they grow and start new colonies along the water courses. During the weed management some pieces are washed by water current to other habitats.

**Euphorbia hirta**

**EUPHORBIACEAE**

**Habit**
Small prostrate annual herb with milky latex. Leaves opposite, inconspicuous green flowers. The plant has reddish tinge. Has taproot system, branches develop from its creeping stem and later become erect. Leaves are simple 38 mm long to 13 mm wide, borne on a short stalk, finely serrated margin, minute flowers, dense rounded, almost sessile clusters n axil of the leaves,. Fruits small capsules with three seeds each.

**Habitat**
Terrestrial, moist soil, water edge, along banks of canals and edges of footpaths.

**Reproduction**
Sexually by seed production. The seeds are minute and can be dispersed by animals like birds and other grazing herbivores.

Distribution
Many parts of central province and Nairobi in Kenya and also in Australia. It was found creeping along channel banks in Mwea Irrigation Scheme, Kenya. Southern Africa (Arnold and de Wet 1994).

Control
Controlled by uprooting. Reported resistant to 2, 4-D in Kenya. In Australia it is susceptible to 2,4-D and MCPA (Ivens 1989).

Fimbristylis dichotoma
CYPERACEAE

Habit
An annual herb, with solid culm, simple alternate basal leaves. Leaves as long as the culm, inflorescence, umbel compound, with numerous spikelets, 3-4 bracts. Similar leaves, long as umbel, rust coloured.

Habitat
It is found in swamps, marshy habitats, edge of rivers, lakes, ponds and of the irrigation and drainage channels.

Reproduction
It reproduces vegetatively, by producing suckers at the base of the plant. The plant reproduces sexually through seeds. It produces large number of seeds which fall on the ground and germinate.

Distribution
The plant is found in many parts of Kenya in wet land areas, margins of ponds, in Nairobi marshy areas, and in MIS, Kenya. It is also found in Sudan (Andrews 1956) and southern Africa (Arnold and de Wet 1994).

Dispersal
The seeds are dispersed by mammals and birds which carry them on their feet, stuck on mud.

Ipomoea aquatica
CONVOLVULACEAE

Habit
It is an aquatic perennial plant with long hollow stem, 1 cm thick, trails along the mud or floats over the surface of water producing roots at the node. Leaves are alternate, long petiole 6-15 cm long, blades vary from ovate to lanceolate, acute tip and cordate or sagittate base. Axillary inflorescence, one to many flowers. Flower has 5 green sepals joined at the base, 6-8 mm long and five fused petals bell shaped, pink to purple, whitish purple centre. They rarely form fruits. The fruit is a capsule, ovoid, 1 cm long, 2
celled, 4 seeded, seed about 4 mm long, 5-7 mm broad, densely greyish pubescent or glabrous (Moody 1981). The seed yield is low, four or less seeds.

Habitat
Grows in flooded lowland areas, marshes, roadsides, rice fields, muddy river banks, floating in stagnant streams and lakes or in the irrigation and drainage channels, in soggy soils and it is unable to survive in frost or snow.

Reproduction
It reproduces vegetatively by fragmentation, the vine or a small fragment with node and axillary bud is capable of giving rise to a whole plant. The seed germinates to give rise to young seedlings which continue to reproduce vegetatively. A small cutting with a few axillary buds produce roots, and the axillary buds grow into runners rooting at the nodes as they grow.

Dispersal
The plant vegetative stem and seeds are both dispersed by the flowing water. Man disperses the plant during weed management as he disconnects the vines from the parent plant and they are carried by the water. He also disperses the seeds with his feet from one area to another. The grazing animals drag large pieces of the weeds from one place to another helping in the dispersal of the plant.

Control
The weed is controlled by cutting and uprooting, however due to its vegetative nature of reproduction, it is very difficult to completely eradicate the weed by physical control.

Use
Wild life food e.g. rodents and deer (Tavern et al. 1979).

Distribution
The plant is found in MIS, Ahero and Kano Irrigation Scheme, and lake Victoria in Kenya. It is a native of south east Asia, Taiwan and southern China. It is also found throughout the old world, south east Asian countries, China, India, Egypt, east and west Africa, and Australia. It is cultivated in Far East for its young leaves and stem which are eaten as vegetables. The plant is used as fodder for pigs and cattle in South Africa (Arnold and de Wet 1994).

Launea cornuta

Habit
Tall globular perennial herb, 120 cm high, extensive underground rhizome produces copious milky latex. Leaves 18 cm pinnately cut backward directed teeth, leaves of basal rosette narrow into a short winged stalk. Alternatively arranged leaves sessile, bar clasping stem. Flowerhead 12.5 mm long on very short flower stalk, strap-shaped florets in
rows. The flowers are yellow, twice as long as bracts, form narrow cylindrical involucre.

Fruit
One seeded spindle shaped apex tapering to a short point with a ring of white long unbranched hairs (Ivens 1989).

Reproduction
Sexually by seeds which are dispersed by wind. Roots give rise to new plants through vegetative reproduction.

Habitat
Commonly found wasteland and farmland as weed in Mwea. It grows along the bank on light water line in irrigation and drainage channels.

Distribution
Widely distributed in Africa and in central Kenya and Nairobi.

Control
Uprooting and slashing very difficult to control due to system of rhizomes. 2,4-D has little effect on aerial shoot. In Ethiopia controlled by use of dicamba or picloram.

Dispersal
The light seed with hair is blown by wind to a new habitat. The seeds also float in water and are dispersed. Mammals disperse seeds and rhizomes carried on their feet.

Leersia hexandra
GRAMINEAE

Habit
The plant forms a pure close together, but nor in tussocks, short leaves, almost vertical. Very slender stem, erect, about 2 mm wide and grow to a height of about 30-120 cm from a stoloniferous rhizome below the soil or water, short ligules where leaf blades arise. Leaf black, up to 20 cm long, 7 mm wide. Somewhat rounded at the base and taper to a fine point at the tip. Midrib narrow and inconspicuous but bears short hook like hairs at the back pointing towards the base of the leaf (Hall et al. 1975; Andrews 1953). Lamina is bluish green, the creeping rhizome is tubed, the runners grow on water and can attain length of 5 meters long. Leaf sheath are loose and covered with white rough hair.

Inflorescence has erect panicles 5-12 cm long, spreading or contracted, spikes in two series overlapping with small projection at the base. Spikes 2.5-4.5 mm, outer bracts white or purple. Fruit a caryopsis but seldom produced (Holms et al. 1976).

Habitat
The plant has 17 species of tropical marsh grasses, medium to deep flooded, habitat a component of sudd community, permanent
moist or marshy habitat. In and along margins of irrigation and drainage channels.

Distribution
Widely distributed in Africa and outside Africa (Thompson 1985). Recorded in Mwea and Ahero Irrigation Scheme, Nairobi, drainage channels and in marshy areas of central Kenya; Southern Africa in Botswana (Arnold and de Wet 1994).

Control
It is controlled mostly by cutting, though regrowth is immediate. Good control with fluoridone (Westendahl and Getsinger 1988).

Reproduction and Dispersal
It reproduces vegetatively. The underground rhizomes and runners when disconnected from parent plant give rise to whole colonies. They are dispersed by water and big herbivores which carry runners on their feet.

Lemna minor

Habit
A small floating herb, frond green on both sides flat slightly longer than broad. Nearly symmetrical, 2 – 5 mm long, with 3 veins (Westendahl and Getsinger 1988). Rootlets 1 per frond. Flowers and fruits invisible. Stamen 1 – 2, anthers 1 – 2 locular; ovary 1 – several, fruit

Habitat
It commonly floats in fresh water habitat; in rivers and main canals where water flow is fast. They are found sheltered in pools of water amongst other weeds along the banks. Very common in rice paddy and slow flowing channels, i.e. in drains and stagnant fresh water.

Distribution
It is found in southern Africa in Transvaal, Natal, Cape, Lesotho (Arnold and de Wet 1994), Mwea Irrigation Scheme and some other parts of central Kenya. n It is native in many parts of the world.

Reproduction
It reproduces asexually by budding, small frond develop underneath the old frond at the base of the root. When mature the small frond separates from the parent frond.

Ludwigia stolonifera

Habit
The plant is attached to mud where it grows horizontally over the surface of water, producing white spongy roots for respiration and they also act as floats. The long runners are smooth and shiny, with alternate leaves. The stem is 5 mm
thick spongy leaves are 8 cm long and 2.5 cm wide. Flower has five large petals, yellow in colour. The inferior ovary is 3 cm long, 3 mm thick, with 5 rows of large angular seeds. Forms dense mat on muddy shores, slow flowing waters and permanent flood plains (Hall et al. 1975). During dry periods the plant dries and some parts of the plant become terrestrial form but as a much reduced size with small leaves and stems. When plain or channels fill with water the plants flourish.

Habitat
It grows in stagnant water in swamps, lakes, irrigation and drainage channels mainly along the banks rooted to the mud and the stem floating. Grows in the banks of slow flowing streams.

Reproduction
Asexually by fragmentation. A small portion of the stem with a few nodes if left in mud develop axillary buds which give rise to a whole colony of plants. The seeds germinate in mud and grow to a whole plant.

Distribution

Control
Cutting, uprooting and burying in mud.

Dispersal
Mainly by water. The runners on the surface of water are disconnected by water current, animals or by man during weed management and float in water until they hold onto the surface of mud where they start to grow. Seeds are very small and are also dispersed by water. The disconnected fruits float easily in water.

Marsilea quadrifolia
MARSILEACEAE

Habitat
It is a perennial herb which grows rooted on the mud. Leaves borne on slender long petiole 10-30 cm which carry them onto water surface. There are four leaves together which give the leaf appearance of a clover. The stolon root at the node and give rise to shoots and leaves. It grow in submerged and emergent form. Inflorescence sporocarps 2-3 mm in diameter and are covered with brown hair when young (Moody 1981). The plants reduce drastically when water dries but remain in terrestrial condition, in a dormant state. When rain comes the following season, the plant grows quickly and continues its normal life.

Habitat
It is an aquatic plant which grows in channels in the irrigation systems mainly drain where water flow is slow or
stagnant, in rice paddies, in small slow flowing steams, and in marshes.

Reproduction
It reproduces both asexually by fragmentation and sexually from the spores (Moody 1981).

Dispersal
The broken pieces of the stem with a few nodes are dragged by grazing herbivores to different aquatic habitats. The pieces also float on the surface of water and are dispersed to various places particularly during the weed management.

Distribution

Najas graminea NAJADACEAE

Habit
It is a submerged fresh water, aquatic herb, elongated stems rotting at the lower nodes. Leaves are small linear spreading and curved, with several small teeth, 36-40 on each margin. Sheath elongated, pointed lanceolate auricles, 8-10 teeth on each margin. Flowers without a spath, fruit narrow, oblong or ellipsoid, oblong, tapering at the apex.

Habitat
In stagnant and slow flowing streams, in rice paddy fields when flooded, in silted clear irrigation channels, and in ponds.

Distribution
In Mwea Irrigation Scheme in Kenya, Blue Nile Province in Sudan near Jebel Arask Kol Equatorial.

Reproduction
Sexual means where seeds are produced and germination occurs in water and vegetative reproduction, by fragmentation.

Control
The weeds dry when the water dries up i.e. drawdown.

Dispersal
Seeds are dispersed by water and fragments of stem can be dispersed by animals and water.

Ottelia exerta HYDROCHARITACEAE

Habit
It is an aquatic annual herb rooting in mud attached to an underground rhizome. Simple cordate leaves alternate all arising from the rhizome. The leaves are green shiny and
float on the surface of water. The petioles are long and spongy. Sepals 3, free petals, ovary inferior, parietal placenta. Numerous ovules, fruit rupture irregularly dispersing small seeds.

Habitat
Aquatic, in rice paddy and in irrigation channels especially in stagnant or in channels with slow flowing water.

Reproduction
Reproduces sexually by seed and asexually by underground rhizome which give rise to aerial shoot through vegetative reproduction.

Distribution
It is found in Mwea Irrigation Scheme and Ahero Irrigation Scheme in Kenya and in Sudan (Andrews 1956) and also in Southern Africa, in Transvaal, Natal and Namibia (Arnold and de Wet 1994).

Control
Uprooting and drying.

Dispersal
Uprooted plants and rhizomes float in water and are left in new habitats. The small seeds stick on legs of birds and herbivorous mammals and are dispersed to various aquatic habitats.

**Panicum repens**

**GRAMINEAE**

Habit
A perennial grass. The shoots grow erect from nodes of underground rhizomes which creep extensively. Has strong rigid stem between 40-50 cm high. The leaf blades are linear, flat or folded, 2-7 mm wide. The hairy sheath surrounds the stem (Tarver et al. 1979). Membranous hairy ligules at the end. Inflorescence is open panicle which produce large numbers of seeds (Chabrek and Condrey 1979). Spike is ovate or oblong.

Habitat
Grows mostly rapidly in moist soil along the river banks, ditches and canal banks where it extends into water and form very thick floating mat. It is also found in flood plains.

Distribution
The plant is native of Australia (Tarver et al. 1979). Has been reported along gulf coast from Florida to Texas. Southern Africa (Arnold de Wet, 1994). It has also been reported in central and southern Sudan (Andrews 1956). In Kenya it has been identified in Mwea Irrigation Scheme Central Province and in Nairobi. It is a good food for cattle and rabbit.

Control
Slashing, uprooting and dredging. Difficult to control and hence a problem along margins of ponds, lakes, sea beaches and sand dunes (Tarver et al. 1979). It is a problem in main and branch canals as well as main drains as it has a tough stem to cut.

Reproduction
It reproduces vegetatively from runners and underground rhizome. The runners produce axillary buds which give rise to other runners and shoots.

Dispersal
By water and animals. The vegetative rhizome or its runner with a few nodes buds and give rise to a whole colony. Animals such as livestock carry such fragments from one place to another and when left in suitable habitat grow. The propagules can also be dispersed by water.

_Paspalum scrobiculatum_
GRAMINEAE

Habit
A tufted erect rather slender perennial 1.0-1.4-1.0 m high stem, decumbent and branched below, flat leaves, glabrous longer than internode compressed and keeled. Ligules 0.5-1 mm long, with tawny hairs on the back. Inflorescence a panicle consisting of 3-4 usually spreading racemes 4-8 cm long. Rachis flat, 1.5-3 mm Spikelets, solitary, orbicular to ovate, about 2 mm long. Seed: light brown (Moody 1981).

Habitat
The plant is found in wet soil and aquatic habitats, edges of lakes in stagnant shallow ponds and marshy areas, and in shallow irrigation and drainage channels.

Reproduction
The weed reproduces vegetatively and also by seed. The thick stolon produces axillary bud and roots at the nodes. A small piece of stem with a few buds can produce a plant colony.

Distribution
It is common in Kenya, in Mwea Irrigation Scheme, Hero and Kano Irrigation Schemes and in Nairobi, south and south-east Asia (Moody 1981). Southern Africa (Arnold and de Wet 1994).

Dispersal
Seeds are dispersed by water and also by animals which carry seeds on their hooves and birds on their feet. The fragments of rhizomes float freely in water and can be carried for a long distance. The buds on rhizomes grow and become new colonies.

_Polygonum senegalense_
POLYGONACEAE

Habit
It is an emergent macrophyte, produces an erect stem which can grow up to a height of 1-2 m. It has cylindrical internode 1 cm thick. The lower parts root at the nodes. The stem is hollow to allow buoyancy during periods of high water level. The leaves are 20-30 cm long, broad and taper to a point at both ends. Has a smooth, closed tubular sheath, 3-4 cm, and a small leaf stalk arises from its back. The spike at the top of the stem bears branching inflorescence. The flowers are small, pink and white; produce very many tiny seeds. Two species of Polygonum common in the irrigation and drainage channels are Polygonum senegalense and Polygonum salisifolium. One form of Polygonum senegalense looks pale due to thick hair on lamina blade (Hall et al. 1975).

Habitat
Along irrigation and drainage channels. Along edges of lakes, rivers, branch canals and in swamps.

Distribution
Mwea Irrigation Scheme, wetlands of Kenya, southern Africa (de Wet 1994). Lake Volta (Hall et al. 1975). Commonly found at the edges of ponds, lakes, rivers and canals. They tolerate flooding.

Reproduction
Underground rhizomes reproduce vegetatively. The plant produces large number of seeds which germinate easily and are among the first seedlings to appear after dredging. The seedlings are usually eliminated by Leersia hexandra and Panicum repens through competition.

Control
Uprooting the rhizomes and cutting the aerial shoots.

Dispersal
When underground rhizomes are disconnected by animals or water they are carried by water and animal, they produce buds at the nodes which give rise to new plants which continue to reproduce vegetatively. Seeds are small and are carried by water. Birds can carry seeds on their feet. Animals walking can break fragments and carry them to new sites where they grow.

Potamogeton schweinfurthii
POTAMOGETONACEAE

Habit
The plant grows almost completely submerged. Stem attached to the mud but leaves floating under water and a few others on the water surface. Submerged leaves are subsessile or with more or less elongated petiole. Linear to lanceolate or narrowly elliptic-oblong, 6.5 cm - 7.5 cm long. Floating leaves if present with more less elongated petiole, lanceolate to oblong. Cuneate or rounded at the base. Sheath free from the leaf. Fruit, carpels about 4 mm long, short and beaked (Andrews 1956).
Aquatic plant, in ponds, rivers, lakes and large irrigation canals.

Distribution

Reproduction
Reproduces sexually by seeds which germinate and give rise to new plants. Underground rhizomes divide vegetatively and give rise to young plants.

Control
It is controlled physically by mechanical dredging, manually by cutting and by pulling with rakes; mechanical weed cutters are also used.

Dispersal
The seeds are produced in water and they are dispersed by water.

*Ricinus communis*
PHORBIACEAE

Habit
It is a tall branching shrub with alternate peltate leaves with long petioles, 40 cm long and 30 cm wide. The smooth stem has white powdery substance. Flowers are borne in cluster, unisexual without petals. Male flowers are below female flowers. The fruit is a capsule with many spines on its surface. The fruit has several seeds, shiny and covered with a hard testa. Each seed is 1 cm long, flowering occurs throughout the year.

Habitat
The plant is found throughout South Florida, in Kenya grows in terrestrial condition in the uncultivated farms. In Mwea it was found along the banks of main and branch canals. It grows along the banks of the rivers.

Distribution
The plant is a native of Territorial Africa but occur in all tropics, central Kenya, Mwea and Nairobi,

Reproduction
Castor oil plant reproduces sexually by seeds.

Dispersal
The seeds are dispersed by man, and other animals as it sticks on the animals hair. After the ripening of the fruit, the fruit dries and the capsules explode dispersing the seeds explosion. Seeds float in water and germinate along the irrigation channels and along banks of rivers.
Control
The main method of control is by cutting, near the root. Seed oil is used for ornamental purposes and as medicine.

Rotala tenella
LYTHRACEAE

Habit
Annual herb, floating creeping stem, mostly submerged particularly when young. Leaves are small, oval, greenish on short internode stem, overlapping. Flowers are small bone on leaf axil above the water level.

Habitat
Aquatic plant, grows in shallow water ponds, in rice paddy and in shallow irrigation channels, where light can penetrate to the young submerged plants. Found together with Najas graminea.

Distribution

Reproduction
By seeds and vegetatively. Seeds germinate under water and grow under water where the plant continues to produce creeping shoots which root as they grow.

Dispersal
The fragments of the shoot are dispersed by water together with seeds. The seeds germinate in water and continue to grow under water.

Sonchus oleraceus
COMPOSITAE

Habit
Annual erect 120 cm tall, stout hollow soft stem, exude milky latex when cut (Ivens 1990). Leaves spirally arranged, pinnately lobed, irregular, serrated margin with pointed apex. Lower leaves no distinct stalk, basal pair of lobes project backward, 2.5-15 cm long (Andrews 1956). Long taproot, roots can give rise to new plants when cut and left uprooted. Flowers are yellow, stalked in loosely branched terminal inflorescence 15 mm in cross-section. Numerous yellow strap-shaped florets, surrounded with several rows of bracts. Fruits are flattened with a ring of white simple hairs. Apex more or less square.

Habitat
Terrestrial margins of irrigation and drainage channels, common in arable land and water areas.

Distribution
Occurs widely in East Africa, common in Muranga district, Mwea Irrigation Scheme, all in Kenya, northern and central Sudan
Native to Europe and north Africa and has become cosmopolitan in (Ivens 1990).

Control

Uprooting. Herbicides - 2,4-D. Pre-emergent treatment with 2,4-D.

Dispersal

The light seeds leave a parachute of hair which help it to float in air and be blown by wind to various habitats. Birds and mammals carry the seeds stuck on their feet and fur to various places.