CHAPTER 3

IDENTIFICATION AND DIAGNOSIS OF WEED PROBLEMS IN IRRIGATION AND DRAINAGE SYSTEMS

3.1 Introduction

This chapter explains the need for weed management and provides guidelines on identifying and diagnosing weed problems. These are presented by considering the different types of weed in irrigation and drainage systems, the range of weed species, and the ecology of weeds and weed communities. A classification of weed communities is described using analyses from case study sites in Zimbabwe and Kenya. These examples provide a good illustration of both the different types of channels, in terms of aquatic weed flora, which make up the channel network, and the change, or development, of the aquatic flora in a given channel over time. The aquatic weed flora of such irrigations systems is made up of around 40 - 60 different species of which about 30% are likely to be either in need of management or useful indicators of a particular channel type. The various detrimental effects of weeds are then described, followed by a concluding section on recording the condition of irrigation and drainage channels.

3.2 Definition of a weed

The term weed refers to a plant which is not desired at its place of occurrence (Coördinatieconommisse Onkruidonderzoek 1984). It may equally be applied to terrestrial (land) and aquatic (water) plants. In terrestrial habitats, weeds are easily recognised because they usually compete with crops or ornamental plants. The multi-functional use of many aquatic habitats, however, complicates the assessment of the 'weediness' of plants which may interfere with one use, such as irrigation, while promoting another, such as fish production (Mitchell 1985). Nevertheless, in an aquatic habitat, a plant which interferes, in any way, with the use of water, or constitutes a nuisance to mankind or hazard to human welfare may reasonably be regarded as a weed.

In the context of these guidelines, the term weed is used to refer to any seed-bearing plant, fern, moss or large alga (i.e. visible to the human eye), which affects the performance of irrigation and drainage systems with respect to water delivery.

3.3 Types of weeds

The distinction between aquatic weeds and terrestrial weeds is difficult to determine because there is usually a gradual transition from the aquatic to the terrestrial habitat. Since these guidelines are concerned with the management of weeds which interfere with irrigation and drainage performance, including the channel bank and wholly or partially submerged plants, a broad definition of an aquatic weed is most appropriate. A weed is recognised as being aquatic if it is usually found by or in aquatic habitats and rarely occurs elsewhere (Gibbs-Russell 1977). Hence, most of the weeds which cause nuisance in irrigation and drainage systems are aquatic weeds. Those weeds growing on the channel bank away from the influence of the water are described as bankside weeds. In addition to aquatic weeds, these plants are also referred to as aquatic plants or aquatic vegetation.

Aquatic weeds may be categorised into four separate types based on the habit of their growth:

- submerged weeds;
- free-floating weeds;
- floating-leaved weeds (rooted to the channel bottom; and
- emergent weeds.

Examples of the four main weed types are illustrated in Plate 3.1.

3.3.1 Submerged weeds

Submerged weeds are those that spend their entire life cycle, with the possible exception of flowering, beneath the surface of the water. They are usually anchored to the bed of the water body and are completely submerged. Some submerged weeds such as *Ceratophyllum* species, however, are not rooted to one place and many submerged species bear their flowers above the water surface. Examples of submerged weeds include *Najas* species and some members of the genus *Potamogeton.*

3.3.2 Free-floating weeds

Free-floating weeds drift on the water surface. Most of the plant body is carried above the water surface including the flowers, and the roots, if present, hang free in the water. Examples of free-floating weeds are *Eichhornia* species, *Pistia stratiotes* and *Azolla* species.

3.3.3 Floating-leaved weeds

Floating-leaved weeds produce leaves which float on the water surface but their roots are anchored to the bed of the water body. Some submerged leaves are often present and the flowers usually emerge from the water surface. Examples of floating-leaved weeds include *Nuphar* species, *Nymphaea* species and some members of the genus *Potamogeton.*

3.3.4 Emergent weeds

Emergent weeds are those whose roots and basal portions develop beneath the water surface but whose stems and leaves are borne primarily in the air. Emergent weeds commonly occur along the margins and shores of water bodies and in swamps and marshes. Typical emergent weeds include *Typha* species, *Phragmites* species and *Cyperus* species.

These are useful categories into which aquatic plants can be separated. In reality, the distinctions between them can be unclear and some species exhibit more than one form even in the same plant. For example, some *Potamogeton* species have both floating and submerged leaves.

3.4 Weed species in irrigation and drainage systems

Irrigation and drainage channels and night-storage reservoirs support a range of aquatic weeds. Species recorded in irrigation and drainage systems in Africa are listed in Appendix 1. Some of these weeds are more problematic than others and these can be divided into two groups (Mitchell 1985):

- species indigenous to Africa which thrive in aquatic habitats created or disturbed by humankind (e.g. artificial waterbodies such as canals or drains and waters enriched by nutrients derived from human activity); and
- non-indigenous species which are able to fully exploit aquatic habitats because of the absence of limiting environmental factors present in their native environments.

Typically, populations of the weeds listed in Appendix 1 are able to reproduce very quickly and are very difficult or very expensive to control. Whilst such noxious weeds may not necessarily establish themselves in all irrigation and drainage systems, irrigation managers should provide for vigilant surveys to identify potential problems at an early stage.

Several species of aquatic weed which occur in irrigation and drainage systems, although detrimental to system performance (Appendix 1), are potentially of value to local economies as:

- food resources for humans, for livestock and for fish production;
- soil additives, including green manure, mulch and compost;
- resources for pulp, paper and fibre production for building and weaving;
- resources for energy production.

Appendix 1 summarises the ways in which aquatic weeds in irrigation and drainage channels and night-storage reservoirs may be utilised.

3.5 Weed ecology

The status of an aquatic weed within a given habitat is the reflection of an integrated response by the weed to physical, chemical and biological factors prevailing in that habitat. Submerged, free-floating, floating-leaved and emergent weeds encounter different environmental conditions and exhibit a range of adaptations which determine community structure (assemblage of weeds) in a given aquatic habitat.

The environmental factors which may be significant to weed growth in irrigation and drainage systems in the tropics and sub-tropics are:

- physical factors:
- water availability and water movement;
- substrate;
- light;
- temperature;
- chemical factors:
- nutrient status;
- pH;
- biological factors.

3.5.1 Physical factors

3.5.1.1 Water availability and water movement

By definition, aquatic weeds require an abundant supply of water. Emergent weeds are usually able to tolerate dry periods, but the leaves of floating and submerged weeds normally die quickly if dried. Short periods of drought tend not to affect roots or rhizomes (underground stems) growing in the substrate (material in which weeds are rooted) and, from these, weeds are able to regenerate quickly once the water returns. Prolonged drought is more damaging to weeds, and new growth must come from deep roots and rhizomes or seeds which have survived buried in the substrate (e.g. the canal bank), or from outside the community (Haslam 1978).

By minimising the incidence of significant drought events, irrigation and drainage channels and night-storage reservoirs provide favourable habitats for aquatic weeds. Many irrigation systems are operated year-round so the irrigation channels and night-storage reservoirs are provided with an almost perennial supply of water. Such water bodies are able to support submerged, free-floating, floating-leaved and emergent weeds. Drainage channels, in which water flow tends to be more ephemeral, are characterised by more drought-resistant emergent weeds.

Aquatic weed distribution and abundance is also affected by water depth. Shallow water is often detrimental to submerged weeds, inciting poor growth, even though the plant shoots are in water and have space for development (Haslam 1978). Tall emergent weeds such as *Phragmites australis* may also be limited by water depth. At the other extreme, few emergent weeds are able to live submerged in the water because they cannot photosynthesize.

One of the most important factors influencing the plants which occur in aquatic habitats is water movement. Compared with the wide range of flow velocities which occurs in natural watercourses, the regulated flows in irrigation canals are relatively uniform. Flow rates (which seldom exceed 1.8m/s (Chow 1983)) are generally too low to cause physical damage to weeds through turbulence or spate (Butcher 1933; Haslam 1978). However, the development of some free-floating, floating-leaved and emergent weeds in primary/secondary canals may be inhibited by the rate of water movement. Many weed species commonly associated with irrigation canals (e.g. *Potamogeton* species) are typified by a preference for low water velocities (Haslam 1978); other species, more tolerant of faster flows and increased turbulence, sometimes occur in short lengths of canal immediately downstream of off-takes, flumes or weirs.

3.5.1.2 Substrate

The growth of aquatic weeds is influenced by the physical texture and chemical composition of the substrate. The physical properties of a substrate are the product of the bedrock, erosion by water turbulence and currents, elutriation (separation by water) of the lighter and heavier eroded particles, deposition of inorganic and organic sediments and the activities of flora (plants) and fauna (animals) (Sculthorpe 1967). The processes of erosion and elutriation create graded substrates in which there is an overall decrease in particle size with decreasing water turbulence and velocity. Generally speaking, finer substrates that contain a high proportion of silt particles tend to be richer in nutrients than coarse substrates since most nutrients are bound to the silt particles (Haslam 1978).

Some aquatic plants are most abundant on fine substrates, others grow best on coarse substrates. The situation arises because aquatic plants exhibit a preference for a particular substrate, a preference for a particular type of water movement, or a preference for the combined effect of flow and substrate (Haslam 1978).

The beds of unlined irrigation and drainage channels are usually dominated by fine substrates. In reaches immediately downstream of off-takes, flumes or weirs, where water velocity and turbulence are locally increased, coarser substrates may be found.

The substrates occurring on the beds of night-storage reservoirs sometimes exhibit a depth-related gradation, coarser substrates occurring along the shore-line where wave-induced turbulence is greatest.

3.5.1.3 Light

All green plants are dependent on light as an energy source for photosynthesis. Light can be a limiting factor for aquatic weed growth, particularly for submerged species. Light availability and quality in water are influenced by the angle of incidence of sunlight, water surface reflectivity, shade, and attenuation due to absorbance by water molecules, dissolved and suspended substances and plant and animal tissues (plankton) in the water (Sculthorpe 1967; Haslam 1978). The actual depth at which limiting light intensity is reached is a function of these factors and varies from site to site.

High suspended sediment loads are a characteristic feature of many irrigation schemes in the tropics and sub-tropics and may limit weed growth in some of the larger, deeper irrigation canals, by contributing to a reduction in light availability.

Trees, shrubs and other tall vegetation along the channel or reservoir margin will reduce light availability. Bottom feeding fish can create turbidity by stirring up the substrate and hence reducing light penetration.

3.5.1.4 Temperature

Plant growth is usually limited by temperatures of less than 6-7ºC. Temperature fluctuations in aquatic habitats are generally much less extreme than in the aerial environment. Seasonal and daily fluctuations of temperature in flowing waters are greatest in summer and/or at lower altitudes where air temperatures fluctuate more and where there is an influx of surface water affected by local weather conditions (Sculthorpe 1967). At any one location, however, water temperature fluctuations are usually moderated by turbulence and the diurnal amplitude may be reduced to as little as 1°C.

In the tropics and sub-tropics, air temperatures remain relatively high throughout the year. Coupled with the relatively slow and uniform water movement in irrigation and drainage channels, this results in relatively high water temperatures which promote vigorous plant growth year-round.

The rapid rate of weed growth which occurs in irrigation and drainage channels at Mwea Irrigation Settlement is illustrated in Plate 3.2. Vegetation recovers very quickly following channel maintenance. In the smaller, tertiary and quaternary channels (unit feeders, feeders, field drains and collector drains), vegetation cover, following manual cutting, was observed to increase from zero to 100 percent within 2-3 months. In the primary and secondary canals, the rate of recovery was somewhat slower: after dredging, weed cover increased from zero to 90 percent within 5-6 months.

The differences in the rates of vegetation recovery in primary/secondary channels and tertiary/quaternary channels may partly be explained by reference to the maintenance carried out on the channels. Dredging usually has a greater impact on vegetation than manual cutting since roots and rhizomes are removed in addition to the stems and leaves. Furthermore, primary/secondary irrigation canals are relatively less favourable habitats for weed communities than tertiary/quaternary canals and drains because higher water velocity, greater water depth and reduced light availability may inhibit the growth of certain weed types.

3.5.2 Chemical factors

3.5.2.1 Nutrient status

Sixteen nutrients are known to be essential to plant growth (Riemer 1984). These can be divided into macronutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium and magnesium) and micronutrients (iron, manganese, boron, zinc, copper, molybdenum and chlorine) according to the relative amounts in which they are required by plants. Free-floating species necessarily obtain nutrients from water alone. Other aquatic weeds may derive nutrients from the water and/or the substrate in which they are rooted. The relative importance of the nutrient sources is uncertain but probably varies between species (Haslam 1978).

The nutrient content of the water and substrates in an aquatic habitat reflects the catchment geology and fertility (which is greatly affected by land use). The specific concentration and relative proportion of nutrients available for plant growth in any one habitat are extremely variable. Causes of variation include precipitation and evaporation, activities of animals, e.g. livestock, the substrate chemistry and pollution.

Little is known of the biological roles of the micronutrients in aquatic habitats. It is generally assumed that they are present in sufficient quantities in most waters so that plant growth is rarely limited by any of them. Of the macronutrients, comparisons of plant tissue and freshwater nutrient concentrations suggest that for aquatic weeds generally, nitrogen and phosphorus are most likely to limit plant growth under natural conditions (Raven 1984). These substances are frequently applied to fields on irrigation schemes to boost crop production. If they are leached from the soil into drains and canals (via recirculation of drainage water), they may enhance aquatic weed growth. Nitrogen and phosphorous are often implicated in the acceleration of eutrophication (nutrient enrichment) of waters by human activity.

Submerged plant growth may also be limited by carbon and, under conditions of high biological oxygen demand (e.g. following organic pollution), by oxygen. Unlike free-floating, floating-leaved and emergent weeds which derive carbon and oxygen from free carbon dioxide and oxygen in the atmosphere, submerged plants must obtain these nutrients from the water. Carbon is available to submerged plants in the form of dissolved carbon dioxide or bicarbonate ions; oxygen exists only as dissolved gas in the water.

When nutrients are absorbed by plants, the area immediately surrounding the site of uptake (e.g. the water around each leaf) is depleted of nutrients and a diffusion gradient is established between the impoverished area and the surrounding water. In still waters particularly, the rates of diffusion of dissolved gases, other nutrients and waste products can be so slow that the demand for nutrients by submerged plants is not met and plant growth is limited (Sculthorpe 1967). Water movement (turbulence and currents) assists the dissolution of atmospheric gases and increases diffusion gradients, facilitating the exchange of substances between the water and the plants (Westlake 1967). The flow of water in canals and drains, therefore, constantly replenishes dissolved gas and nutrient supplies, and submerged weed growth is probably not limited by nutrient availability.

3.5.2.2 pH

The pH of freshwaters varies from acid to alkaline (usually from pH 6 to pH 9) and is modulated by hydrogen and hydroxide ions. The pH of water has direct and indirect effects on the photosynthesis and growth of submerged weeds, affecting the active uptake of nutrients by plants, and affecting the form and availability of nutrients such as phosphorus, nitrogen and carbon, respectively. Photosynthesis and therefore weed growth generally declines as pH increases.

3.5.3 Biological factors

3.5.3.1 Interactions between living organisms

The composition of plant communities in irrigation and drainage channels, whilst partly determined by physical and chemical factors, is also a reflection of interactions which occur between plants and animals living in the channels. The relative rates of plant growth and competition between plants of similar or different life form are particularly important in this respect (Sculthorpe 1967). More vigorously growing species tend to have a competitive advantage over less active species. Competition occurs when two different species contend for the same environmental resource. In competing for a resource, one species may make a habitat less suitable for another, e.g. emergents and/or floating species in the water column may shade plants below. Species which are in competition with each other are typically unable to persist together for an indefinite period. Insects and other invertebrates can also have a significant effect, usually on one species in a community, by either eating the leaves or damaging, for example, the stem or flower buds.

The interactions between aquatic weeds and the aquatic animals they support are numerous. However, the impact of grazing animals is perhaps the most important in terms of aquatic plant community composition. Domestic animals such as sheep and cows often roam freely on irrigation schemes in the tropics and sub-tropics. The effects of their grazing can be quite marked in localised areas.

Weeds are susceptible to diseases, e.g. fungal, but very little is known about this factor.

3.5.3.2 Human activities

Perhaps the greatest influence on the distribution and abundance of plant communities in irrigation and drainage channels derives from human activities, particularly attempts to control weed growth. Whilst clearly reducing the standing crop of aquatic weeds, cutting, dredging or herbiciding (see Chapter 4) may also alter the composition of plant communities by excluding certain species and encouraging the growth of others. The impact of weed control activities on the aquatic flora in irrigation and drainage ditches is usually proportional to the severity of the treatment in relation to water availability after maintenance.

3.6 Community ecology

The structure of weed communities, i.e. the assemblage of different aquatic weed species, in freshwater habitats changes both in space and time.

3.6.1 Spatial variation

The spatial variation in community structure in irrigation and drainage channels can be considered at the small and large scale.

3.6.1.1 Zonation

At the small scale, there is a zonation of life forms across a channel determined by bank slope and depth gradient (Figure 3.1). Characteristically, the sequence is marked by submerged communities in deeper water giving way nearer the shore to a zone of floating-leaved plants. These are replaced by emergent communities in the marginal zone from a water depth of one metre to wet soil on the shore.

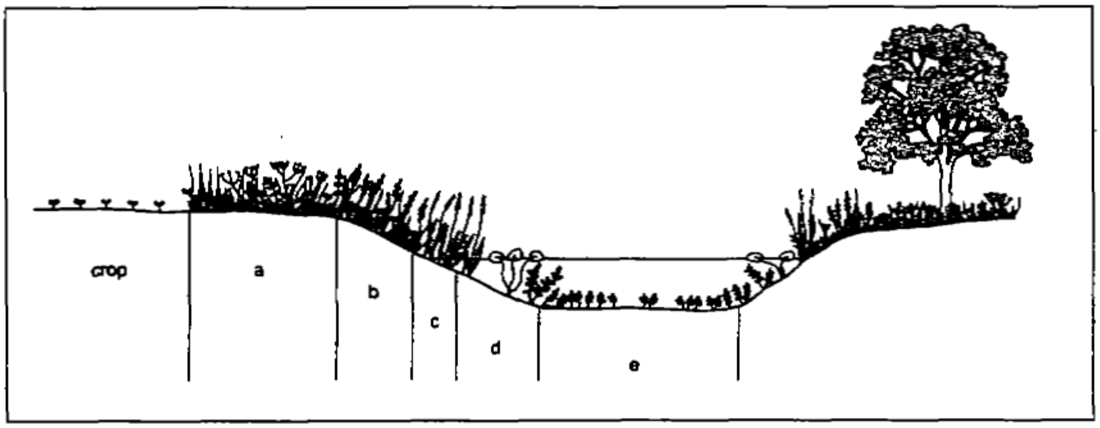

Figure 3.1. Zonation of vegetation in an irrigation or drainage channel ((a) the field margin usually dominated by grasses, with or without trees and, or shrubs; (b) the bank or batter supporting a range of grasses and herbs typically related to water-table; (c) the boundary between land and water with a range of amphibious grasses and herbs able to tolerate variations in water level; (d) the littoral zone in which emergent species occupy the shallower water with floating and submerged species being able to extend into the deeper water; (e) the deep water zone only found in the larger channels supporting mainly submerged plant species)

3.6.1.1 Channel types

The environmental conditions which prevail in irrigation and drainage channels are sufficiently distinct to encourage the development of characteristic plant communities (Figure 3.2). Typically the channels within the irrigation system can be classified into groups of similar channel types based on the composition of the aquatic weed communities. Each group of channels will require a different type of maintenance. The situation can be illustrated by reference to analyses of botanical data collected at study sites on irrigation and drainage channels at Chisumbanje Estate in Zimbabwe and at Mwea Irrigation Settlement Scheme in Kenya.

a. Chisumbanje Estate, Zimbabwe

- Wet Season

The irrigation and drainage channels at Chisumbanje Estate can be divided into six groups on the basis of the species recorded at sites on the channels during the wet season. The classification is summarised in Table 3.1 and the channels which make up the different groups are illustrated in Plate 3.2.

The small, tertiary canals classified in Group A (wet) are characterised by emergent grasses and the sedge *Schoenoplectus* species. These species are indicative of ephemeral aquatic habitats or damp conditions.

Group B (wet) is made up of small, tertiary canals. The range of species being similar to that in Group A (wet), with many emergent grasses and broad-leaved species though with several species indicative of wetter conditions.

Group C (wet) is dominated by larger, tertiary canals characterised by a range of submerged and emergent weeds, including a large compliment of the species occurring in Groups A and B (wet). Plants such as *Cyperus rotundus*, *Potamogeton* species, *Cyperus articulatus* and *Najas horrida* reflect wetter conditions.

The canals described in Groups A, B and C (wet) are generally irrigated regularly, albeit intermittently, throughout the year. Between irrigations they often retain standing water which tends to be shallowest in the canals in Group A (wet) and deepest in the canals in Group C (wet). The species which characterise the canal groupings reflect this situation: emergent species predominate under conditions in the Group A (wet) canals and submerged species develop in the truly aquatic conditions prevailing in the Group C (wet) canals.

Group D (wet) includes sites along a heavily silted, secondary canal and a site on a large, dry tertiary canal. A wide range of weeds is represented at these sites, including terrestrial species generally associated with the tertiary canal or the berms, emergent species characteristic of damp conditions, and emergent species more indicative of wetter conditions. Submerged species are probably prevented from growing in the secondary canal by high levels of turbidity.

Unlike the canals described in Groups A, B and C (wet), the drainage channels in Group E (wet) function only at peak periods during the wet season. Consequently, they are characterised by a range of terrestrial and emergent weeds. *Typha latifolia* is the only species which reflects the occasional aquatic nature of these channels.

Group F (wet) is exceptional because it contains only one drainage channel site. This site is distinct from those in Group E (wet) since it is located at the tail end of the main drain and functions intermittently throughout the year.

- Dry season

The classification of irrigation and drainage channels at Chisumbanje Estate, based on species recorded in the channels during the dry season, is summarised in Table 3.2. The classification described is broadly similar to that for the wet season except that the channels are divided into seven groups.

Group A (dry) contains one large tertiary canal. It is characterised by emergents commonly associated with damp conditions or irregular inundation and emergents, such as *Typha latifolia* and *Ludwigia stolonifera*

Group B (dry) is made up of large tertiary canals but also includes one secondary canal. These channels support a diverse range of submerged, emergent and terrestrial species. The occurrence of a *Potamogeton* species in this Group suggests that the channels in Group B (dry) are subject to longer periods of inundation than those in Group A (dry).

The channels in Group C (dry) are all small tertiary canals. Emergent species which favour damp conditions and *Nesaea* species which occurs in wet habitats, predominate in these channels. However, the *Potamogeton* species is indicative of standing water in the channels.

The weeds which characterise the large tertiary channels in Group D (dry) are largely terrestrial species or emergents which tolerate infrequent inundation. The occurrence of *Schoenoplectus* species and *Ludwigia stolonifera* in abundance is suggestive of a more permanent aquatic habitat.

Group E (dry) is composed of two sites on a heavily silted, secondary canal and two sites representing small, tertiary canals. The canals in this group are typified by emergent weeds which inhabit a range of habitats from those which are only damp or infrequently inundated to those which remain permanently wet.

Two sites on the main drain and site on a dry, tertiary canal make up Group F (dry). The range of species present indicate that the sites are rarely inundated.

The final group in the classification, Group G (dry), contains only two sites, one on the main drain and the other on a tributary drain. Like the channels, in Group F (dry), these sites are characterised by terrestrial species and emergents characteristic of damp conditions. However, emergent species such as *Typha latifolia*, *Cyperus involucratus* and *Phragmites australis* typify wetter conditions than in Group F (dry).

b. Mwea Irrigation Settlement Scheme (Mwea ISS)

The irrigation and drainage channels at Mwea ISS can be divided into four groups. The classification is summarised in Table 3.3.

Group A comprises seven small, tertiary and quaternary canals and 16 drainage channels, most of which are small, tertiary drains characterised by a range of terrestrial and aquatic weeds. These generally reflect the ephemeral aquatic conditions.

Group B include six drains, seven tertiary and quaternary canals and one larger secondary canal. They support a range aquatic weeds including the submerged species *Najas* species and emergents such as *Centella asiatica*. The former species suggests that these channels are inundated for considerable periods.

Group C is dominated by secondary and tertiary irrigation canals and is characterised by emergents. Emergent species also distinguish the primary canal in Group D.

Although the primary and secondary canals at Mwea flow perennially, few submerged species occur in these canals because of elevated flow rates and high turbidity. Thus, these canals tend to be characterised by aquatic emergents growing along the margins of the channels. The smaller, tertiary canals which are irrigated intermittently but retain considerable standing water for extended periods, provide a suitable habitat for submerged species such as *Ludwigia stolonifera* and *Marsilea* species as well as emergent weeds.

The secondary drains and some of the tertiary drains at Mwea are physically very similar to the tertiary irrigation canals and, in places where the secondary drains serve an affluent function in conveying water from one unit to another unit downstream, they have a similar flow regime to the canals. Consequently, the floras in these irrigation canals and these drainage channels are not dissimilar.

The groups dominated by larger irrigation canals which flow perennially, or are inundated for extended periods, are characterised by emergents and some submerged weeds.

These two case studies illustrate that despite having similar channel profiles, there is a range of significantly different channel types within any given irrigation system as based on the aquatic weed flora. At one extreme, the groups comprising larger, tertiary canals are characterised by emergent and submerged species indicative of perennial water or extended periods of inundation. At the other extreme, the groups composed of drainage channels or dry, irrigation canals are typified by terrestrial and emergent species which reflect the ephemeral nature of the aquatic habitat in these channels. Between the two extremes, are groups dominated by smaller, tertiary canals. These channels support emergent and submerged species characteristic of regular, albeit, intermittent, inundation.

The principal factors governing the condition of the channels are channel size, water availability and the degree of weed management. A large discharge capacity, frequent irrigation and regular maintenance (common to the larger, tertiary canals) upholds the condition of a channel in an early successional stage. Another factor which can account for this variation is the stage of development reached by the aquatic weed flora post-maintenance. This is explained more fully in the next section.

Table 3.1. A classification of irrigation and drainage channels at Chisumbanje Estate, Zimbabwe, based on their aquatic floras in the wet season. (Roman numerals indicate the frequency of a species in a given classification group, where V = 81-100 %; IV = 61-80 %; III = 41-60 %; and II = 21-40 %. For the sake of clarity frequencies of less than 21 % (i.e. I) have been omitted from the table.)

Species	Group A	Group B	Group C	Group D	Group E	Group F
Number of channels in group	4	5	14	4	3	1
Channel width (m)	3.5 - 4	4 - 5	4.2 - 5.8	4.5 - 12.2	8.3 - 12	12
Maximum water depth (m)	0 - 0.5	0 - 0.6	0 - 0.3	0 - 0.8	0	0.6
Bank height (m)	0.6 - 0.75	0.6 - 0.9	0.5 - 0.9	0.7 - 1.6	0.9 - 1	1
Bank slope (°)	15 - 45	20 - 35	25 - 40	25 - 45	20 - 45	25
Conductivity (µs)	0 - 120	0 - 130	0 - 190	0 - 140	0	10
pH	0 - 8.2	0 - 8.6	0 - 9.5	0 - 8.1	0	8.5
Number of taxa	5 - 9	6 - 16	6 - 17	15 - 17	11 - 16	15
Percentage cover	20 - 80	30 - 80	10 - 80	25	75 - 90	-
Echinochloa colona	V	V	IV	III	IV	V
Alternanthera sessilis	V	IV	III	IV		V
Commelina sp.	IV	IV	IV	IV		
Eragrostis sp.	IV		IV	IV	II	
Dichanthium sp.	III	III	IV	II	IV	
Paspalum scrobiculatum	III	II		IV		
Echinochloa jubata	III					
Nesaea sp.	II	V				
Cyperus difformis	II	IV	V	II		
Ludwigia stolonifera	II	III	V	IV		
Rhynchosia sp.	II	II	IV	IV	IV	
Eclipta alba	II	II	II	III		
Dinebra retroflexa	II	II		III	IV	V
Eriochloa sp.	II			IV	II	V
Schoenoplectus sp.	II					
Launaea cornuta	II			IV	IV	
Hemarthria altissima		II	III	III		
Nidorella resedifolia		II	III		IV	
Asteraceae		II	III		II	V
Setaria sp.		II		IV	V	
Euphorbia indica		II		III	II	
Pycreus polystachyos		II				
Typha latifolia			III		II	V
Vernonia glabra			III			
Cyperus rotundus			II			V
Fimbristylis bisumbellatus			II			
Chloris pycnothrix			II			
Potamogeton sp. A			II			
Ischaemum afrum				V	V	V
Phyllanthus maderaspatensis				V	IV	
Cyperus articulatus				V		
Corchorus asplenifolius				III		
Persicaria decipiens				III		

Rottboellia cochinchinensis	II	V	
Cyperus digitatus	II	II	
Phragmites australis	II	II	
Abutilon guineense	II		V
Alysicarpus rugosus	II		
Bidens biternata	II		
Centella asiatica	II		
Digitaria sp.	II		
Dolium sp.	II		
Ludwigia octovalvis	II		
Corchorus olitorius		V	
Euphorbia serpens		IV	V
Sesbania sp.		IV	
Amaranthus hybridus		II	
Euphorbia hirta		II	
Conyza albida		II	
Euphorbia heterophylla		II	
Sporobolus sp.		II	
Cucumis sp.			V
Cyperus involucratus			V
Fimbristylis ferruginea			V
Indigofera parviflora			V
Solanum nigrum			V

Table 3.2. A classification of irrigation and drainage channels at Chisumbanje Estate, Zimbabwe, based on their aquatic floras in the dry season. (Roman numerals indicate the frequency of a species in a given classification group, where V = 81-100 %; IV = 61-80 %; III = 41-60 %; and II = 21-40 %. For the sake of clarity frequencies of less than 21 % (i.e. I) have been omitted from the table.)

Species	Group A	Group B	Group C	Group D	Group E	Group F	Group G
Number of channels in group	1	11	5	2	4	3	2
Channel width (m)	4.5	4.5 - 12	3.9 - 4.8	4.8 - 4.9	3.5 - 12.5	4.5 - 12	10 - 12
Maximum water depth (m)	0.1	0 - 0.5	0 - 0.2	0 - 0.3	0 - 0.4	0 - 0.15	0 - 0.4
Bank height (m)	0.7	0.5 - 1.6	0.55 - 0.9	0.7 - 0.8	0.7 - 1.6	0.8 - 1	1
Bank slope (°)	25	20 - 45	25 - 40	25 - 35	15 - 30	20 - 45	25
Conductivity (μs)	250	0 - 260	0 - 250	0 - 200	0 - 180	0 - 190	0 - 10
pH	7.8	0 - 9.9	0 - 8.4	0 - 8.3	0 - 8	0 - 8.2	0 - 8.2
Number of taxa	11	7 - 21	7 - 11	10 - 12	7 - 17	11 - 20	6 - 11
Percentage cover	90	40 - 70	5 - 50	10 - 60	40 - 70	10 - 95	95
Dichanthium annulatum	V	V	V	V	IV	V	
Ludwigia stolonifera	V	V	II	V	IV		
Asteraceae	V	V					
Rhynchosia holstii	V	III		V	II	V	
Dinebra retroflexa	V	II				II	III
Typha latifolia	V	II					V
Imperata cylindrica	V	II					
Pycreus polystachyos	V						
Ischaemum afrum	V			III	II	IV	
Phyllanthus maderaspatensis	V					II	
Fimbristylis dichotoma	V						
Commelina sp.		V	V		IV	IV	
Echinochloa colona		V	III	V	IV	IV	III
Cyperus difformis		IV	IV	V		II	
Alternanthera sessilis		IV	III	III	IV	II	III

Hemarthria altissima	IV		III			
Nesaea sp.	III	V	III	III		
Eragrostis sp.	III		V	II	IV	
Potamogeton sp. B	III					
Vernonia glabra	II		III		II	
Cyperus articulatus	II			III		
Euphorbia indica	II			II	V	
Sporobolus sp.	II			II	II	
Centella asiatica		II		IV		
Paspalum scrobiculatum		II		III		
Potamogeton sp. A		II				
Setaria sp.			III	III	IV	
Corcorus asplenifolius			III	II	IV	
Eclipta alba			III		II	
Schoenoplectus sp.			III			
Fimbristylis sp.			III			
Eriochloa sp.				III		V
Cyperus digitatus				III		
Persicaria decipiens				III		
Euphorbia hirta				II	IV	
Acmella caulorhiza				II		
Chara sp.				II		
Echinochloa jubata				II		
Ludwigia octovalvis				II		
Najas horrida				II		
Sesbania rogersii					V	III
Launaea cornuta					V	
Bidens biternata					IV	III
Acacia sp.					IV	
Corchorus olitorius					II	V
Abutilon guineense					II	III
Amaranthus hybridus					II	III
Alysicarpus rugosus					II	
Bidens pilosa					II	
Euphorbia heterophylla					II	
Ricinus communis					II	
Cyperus involucratus						III
Euphorbia serpens						III
Phragmites australis						III
Portulaca oleracea						III

Table 3.3. A classification of irrigation and drainage channels at Mwea Irrigation Settlement Scheme, Kenya, based on their aquatic flora. (Roman numerals indicate the frequency of a species in a given classification group, where V = 81-100 %; IV = 61-80 %; III = 41-60 %; and II = 21-40 %. For the sake of clarity frequencies of less than 21 % (i.e. I) have been omitted from the table.)

Species	**Group A**	**Group B**	**Group C**	**Group D**
Number of channels in group	23	14	14	1
Channel width (m)	0.4 - 8.25	1.4 - 5.0	1.5 - 9.18	9.12
Maximum water depth (m)	0 - 0.73	0.05 - 1.01	0 - 1.32	-
Velocity	0 - 0.74	0.026 - 1.25	0.01 - 1.0	0.71
Number of taxa	6 - 18	1 - 14	5 - 22	9
Percentage cover	2 - 100	1 - 100	10 - 90	25
Leersia hexandra	V	V	V	
Cynodon dactylon	V	II	III	V
Commelina sp.	IV	IV	V	V

Ludwigia stolonifera	IV	II		
Panicum repens	III		IV	
Echinochloa colona	III			
Paspalum scrobiculatum	II	II		V
Rhynchosia sp.	II		III	
Fimbristylis sp.	II		II	
Alternanthera sessilis	II			V
Ageratum conyzoides	II			
Ajuga remota	II			
Asystasia sp.	II			
Bothriochloa insculptum	II			
Cyperus sp.	II			
Dyschoriste sp.	II			
Indigofera sp.	II			
Marsilea sp.	II			
Oryza sativa	II			
Euphorbia hirta	II			
Ottelia exerta	II			
Acmella caulorhiza		II	III	V
Eclipta alba		II	III	
Centella asiatica		II		
Najas sp.		II		
Polygonum senegalense			III	V
Cyperus latifolius			III	
Ludwigia abyssinica			III	
Sphaeranthus sp.			III	
Cyperus dives			II	V
Echinochloa pyramidalis			II	
Polygonum salicifolium			II	
Pycnostachys deflexifolia			II	
Desmodium sp.				V
Oldenlandia sp.				V
Polygonum sp.				V
Typha latifolia				V

3.6.2 Temporal variation

Temporal changes in community structure which commence in aquatic habitats are known as hydroseral succession. The successional process is dependent upon a raising of the bed of the water body towards the water surface by the accumulation of plant remains and/or silt. As the water body becomes shallower, submerged species in once deeper areas of the habitat may be replaced by floating-leaved species that encroach towards the centre of the water body reducing light availability in the water column. Emergent species similarly extend further and further from the original shoreline until the open water disappears.

The stages of the hydroseral succession which occur in irrigation and drainage channels at Mwea Irrigation Settlement Scheme in Kenya are illustrated in Figure 3.2. They are more fully described as follows:

'open water' - the channel banks above the mean water level are vegetated with terrestrial and aquatic weeds including grasses such as *Bothriochloa insculptum* and *Cynodon dactylon*, herbs such as *Amaranthus spinosa* and *Oxygonum sinuatum*, and shrubs such as *Abutilon* species, *Ricinus communis*, *Cassia didymobotrya* and *Sida* species (These species are present throughout the latter stages of the succession described below). The wetted perimeter of the channel at the open water stage is free from vegetation.

'submerged and/or free-floating weeds' - the channel banks are vegetated as described above, but the wetted perimeter is also colonised by submerged weeds such as *Najas* species. Free-floating weeds such as *Lemna* species may, or may not, be present. The submerged and/or free-floating stage is more characteristic of primary and secondary canals with perennial water supply than in tertiary canals and drains with intermittent flow.

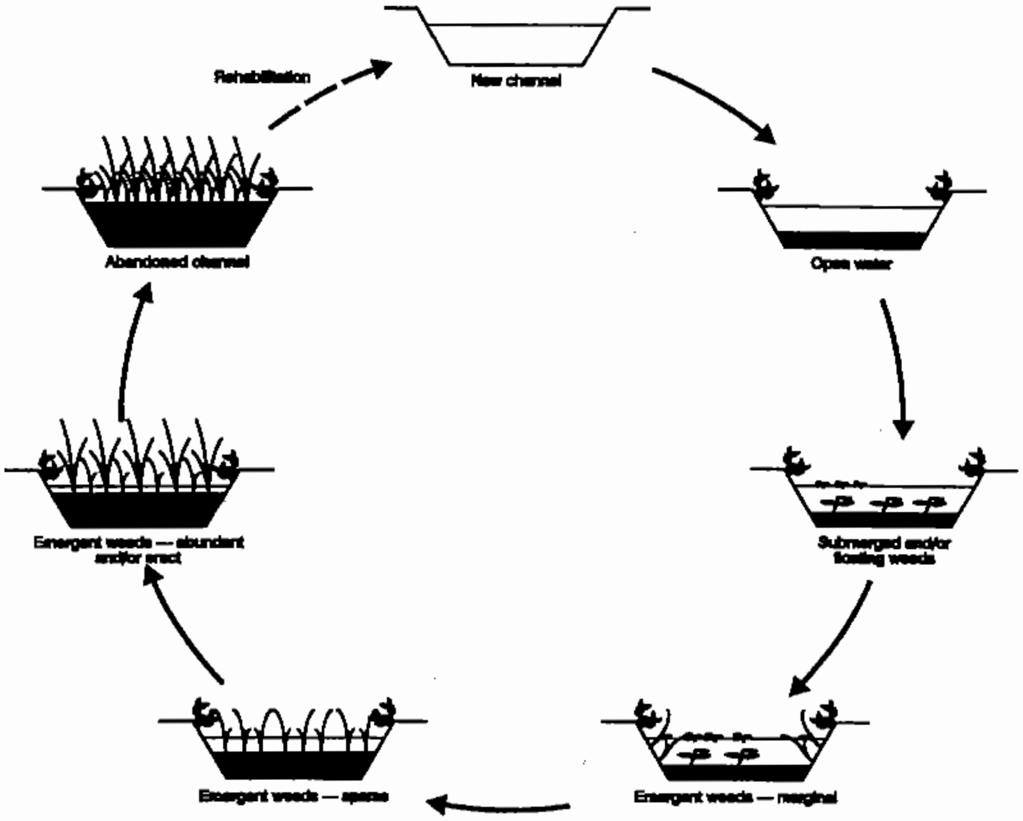

Figure 3.2. The stages of the hydroseral succession which occur in irrigation and drainage channels at Mwea Irrigation Settlement Scheme, Kenya

'marginal emergent weeds' - emergent grasses (e.g. *Echinochloa* species and *Leersia* species), sedges (*Cyperus dives* and *Cyperus latifolius*) and herbs (e.g. *Commelina* species and *Sphaeranthus* species) occur along the water margins and encroach towards the centre of the channel. The banks are vegetated as before, but the submerged and/or free-floating weeds may, or may not, be present.

'sparse emergent weeds' - emergent vegetation covers the entire bed of the channel, often excluding submerged vegetation. Certain emergent weeds such as the herb *Ludwigia stolonifera* and the grass *Leersia* species invade the channel from the water margins; others such as the sedge *Cyperus articulatus* and the floating-leaved herb *Marsilea* species develop in the centre of the channel.

'abundant and/or emergent weeds' - emergent vegetation covers the entire bed of the channel as in the previous stage; however, the species occurring at this stage tend to be more abundant, taller and more erect than those in the sparse emergent stage. The presence of *Typha* species and the occurrence of *Cyperus dives* within the wetted perimeter is indicative of channels in the abundant and/or erect stage.

The rate of succession from one stage to the next is dependent on several factors: channel size (width and depth); water velocity; light and temperature regime; the degree and frequency of channel maintenance; the availability of water in the channel and the persistence of the existing weeds.

The successional process tends to be slower in deeper and wider channels. For instance, larger canals (primary and secondary canals) usually exhibit all stages of succession during a single cycle, whereas smaller tertiary and quaternary canals frequently pass from the open water stage directly to one with a high percentage cover of emergent weeds. In some primary and secondary canals, the depth of water combines with water velocity to slow the encroachment of marginal emergent vegetation. The rate of flow in these channels may also be inhibitory to free-floating weeds. Water depth in combination with high turbidity in primary and secondary canals can prevent the growth of submerged weeds.

Hydrological differences between irrigation and drainage channels produce distinctions in the ecology of these channel types. The slower, more intermittent flow in drainage channels generally favours the development of emergent weeds over submerged and free-floating weeds.

3.7 Detrimental effects of weeds in irrigation and drainage systems

Weed problems in irrigation and drainage systems are generally caused by prolific plant growth. In low density, aquatic plants are usually beneficial to the system because they help stabilise the channel banks, improve water quality, and provide habitat for aquatic fauna such as fish (Marshall and Westlake 1978).

The principal adverse effects of large amounts of weed in irrigation and drainage channels are that they:

- interfere with water flow in canals and drains, inhibiting water delivery to the crop and drainage from the fields;
- entrap sediment, causing a progressive reduction in the capacity of a channel or reservoir;
- reduce reservoir capacity by occupying useful volume and increasing water loss through evapotranspiration;
- block pump intakes, interfere with the operation of regulator gates and weirs, and threaten structures such as canal linings and bridges;
- assist the spread of diseases such as schistosomiasis and malaria by reducing flow velocities and providing habitats for the intermediate vectors of the parasites causing these diseases;
- provide a source of weeds which may spread from irrigation and drainage channels into irrigated fields;
- necessitate the draining of canals and reservoirs for weed control, thereby interfering with irrigation schedules; and
- require the utilisation of scarce resources including finance, labour and equipment in order to achieve control.

Adverse effects of secondary importance are:

- weeds alter the flora and fauna by providing new habitats which may support pests such as rats, snakes and insects;
- weeds interfere with fisheries;

- weeds remove nutrients from the water which might otherwise be available to the crop;
- weeds impair the access of domestic animals to drinking water; and
- weeds when they die, degrade water quality by adding taints and odours and reducing the dissolved oxygen content.

3.7.1 Flow resistance

The relationship between vegetation and hydraulic resistance (resistance to water flow) is of considerable importance to watercourse designers and managers. The most commonly used indicator of the reduction in discharge capacity caused by weed growth is Manning's 'roughness co-efficient' (*n*) derived from the Manning equation:

$$Q = A.R^{0.67}.S^{0.5}/n$$

where: Q is the discharge;

A is the cross-sectional area of flow;

R is the hydraulic radius;

S is the slope of the water surface; and

n is the roughness (retardance) coefficient.

The presence of weed in a channel increases the hydraulic resistance and raises the value of Manning's *n* above the design specification for the channel. Studies have demonstrated a temporal variation in Manning's *n* in response to the development of vegetation during the course of the growing season (Vinson *et al.* 1992).

On the Kalabia Canal in Upper Egypt, the design value of Manning's *n* is 0.025. However, measurements taken over a two-year period in the mid-1980's showed the mean value to be 0.048 (Brabben and Bolton 1988). Assuming that the slope, cross-sectional area and hydraulic radius remain the same, the impact of an increase in Manning's *n* from 0.025 to 0.058 is a reduction in the discharge by a factor of one half. In irrigation terms, this implies that at peak water demands only 50 percent of the water requirement could be supplied by this canal. A 60 percent reduction in peak discharge capacity has been described for the Port Said Canal in Egypt (Brabben 1989). The direct effects of reduced discharge capacity are inadequate water supplied at the far ends of irrigation canals (Gupta 1987) and an inability of drainage channels to remove water from waterlogged areas (Robson 1986).

The degree of resistance offered by weeds varies from species to species, according to the complexity of the plant stand, the form or shape which is presented to water flow, the flexibility, cross-sectional area and spacing of the stems, and the ratio of the depth of water to the height or length of the weed (Pitlo and Dawson 1990; Bakry 1992). For example, free-floating *Eichhornia crassipes* has been found to raise the value of Manning's *n* from 0.025 to 0.065 while submerged weeds such as *Potamogeton pectinatus* and *Ceratophyllum demersum* have been reported to increase Manning's *n* to 0.04 (Khattab and El Gharably 1990). Submerged weeds which cover the entire wetted perimeter of a channel act as a lining material, inducing uniform flow with less shear stress and hence a lower hydraulic resistance than weeds covering the bed of only one side of a channel (Bakry 1992).

3.7.2 Siltation

Weeds in irrigation and drainage channels reduce the mean water velocity and thereby increase the deposition of suspended sediments. Significantly more silt, sand and fine gravel accumulate on vegetated substrate than on non-vegetated substrate (Gregg and Rose 1982). In irrigation and drainage systems, siltation contributes to a reduction in the capacity of reservoirs to store water and a reduction in the discharge capacity of canals and drains (Haque and Rahman 1976). The annual deposition of silt in canals at the Gezira-Managil scheme in Sudan is estimated to be 4.5m^3 per hectare served (Mott McDonald and Partners Ltd. 1990).

3.7.3 Loss of reservoir capacity and evapotranspiration

On a large reservoir, where free-floating weeds are the dominant vegetation, the volume of water displaced by them is generally small relative to the useful capacity of the reservoir. However, in a small reservoir, a significant loss of storage may be caused by weed infestation. In Zimbabwe, for example, the loss of capacity for a small reservoir with a mean depth of 0.5 m, was found to be 12.5 - 30 percent (Brabben and Bolton 1988).

The type of weed in a reservoir influences the operational effect of a loss in capacity. Free-floating weeds and submerged weeds displace a more-or-less fixed volume regardless of the depth of water. Emergent weeds, however, occupy a volume approximately proportional to the depth of water around them (Brabben and Bolton 1988).

Three types of reservoir commonly used in irrigation systems are at particular risk from a loss of capacity as a result of weed growth (Brabben and Bolton 1988):

- local storage ponds or night-storage reservoirs (e.g., in many small-holder schemes in Zimbabwe);
- intermediate storage tanks formed when a single bank canal crosses a tributary stream (e.g., on many small and medium-sized schemes in Sri Lanka); and
- linear storage reservoirs in which canals are purposely over-sized to produce storage (e.g., minor canals in the Sudan Gezira Scheme).

The effect of weeds on the loss of water from open water surfaces through evapotranspiration is not clearly understood. However, evapotranspirative losses from certain weeds, particularly emergent weeds such *Typha latifolia* and *Cyperus rotundus*, have been found to exceed evaporative losses from open water (Brezny *et al.* 1973).

In most canal systems loss of water due to evaporation is believed to be extremely small relative to the total volume conveyed (Brabben and Bolton 1988). By contrast, in shallow reservoirs, evaporative losses can have a considerable effect on the hydrology and even a modest change in the rate of evaporation, caused by weeds, may be significant.

3.7.4 Obstruction and damage to engineering structures

Operational problems arising from the obstruction of gates and intakes are regularly caused by free-floating weeds such as *Eichhornia* species (Gay 1960; NCR-NAS 1975; Brabben and Bolton 1988). Plant material drawn into pumps can obstruct impellers, and the operating mechanism at sluice gates may be jammed by accumulated vegetation. In many cases, some congestion around an orifice or weir can be tolerated. However, the hydraulic characteristics of the structure are modified by the accumulated matter which prevents the precise quantitative control of discharges towards which irrigation managers strive.

Heavy accumulations of debris at gates and intakes can cause impairment to these structures. Further damage to irrigation and drainage infrastructure may be generated by the growth of weeds, particularly emergent weeds with their extensive rhizome systems. Death and decay of the rhizomes leaves small tunnels through which water seepage may occur, leading to breaches in the channel banks. Similar tunnels are also created by rodents and crustaceans which feed on and amongst the vegetation (Brezy and Mehta 1970). In these ways weed growth reduces the conveyance efficiency of channels and increases the risk of breakdown of supply.

3.7.5 Disease

Dense growths of aquatic weeds create or alter habitats which can then favour the development of disease vectors. Two of the most important vectors which depend on the environmental conditions prevailing in aquatic vegetation for at least part of their life-cycle are aquatic snails and mosquitoes. These organisms are responsible for the transmission of several diseases which affect mankind (Biswas 1980) (Table 3.4).

Table 3.4. Selected examples of vector-borne diseases associated with aquatic habitats

Parasites	Diseases transmitted	Vector	Infection route
Nematoda			
Wuchereria bancrofti	Elephantiasis (filariasis)	Mosquitoes (*Aedes* sp., *Culex* sp., *Anopheles* sp.)	Bite
Protozoa			
Plasmodium sp.	Malaria	*Anopheles* mosquito	Bite
Trematoda			
Schistosoma haematobium	Urinary schistosomiasis (bilharziasis)	Aquatic snail (*Bulinus* sp.)	Through the skin
Schistosoma mansoni	Intestinal schistosomiasis	Aquatic snails (*Biomphalaria* sp., *Australorbis* sp.)	Through the skin
Schistosoma japonicum	Visceral schistosomiasis	Amphibious snail (*Oncomelania* sp.)	Through the skin
Viruses			
Over 30 mosquito-borne viruses are associated with human infections	Encephalitis; dengue	Mosquitoes (including *Culex* sp., *Aedes* sp.)	Bite

The diseases listed in Table 3.4 are not new. However, the unprecedented expansion of water resource developments, including irrigation, has introduced these diseases into previously uncontaminated areas Oomen *et al.* 1988; 1990). For example, an association between the extension of irrigation and an increase in schistosomiasis (or bilharzia) has been widely demonstrated (Biswas 1980). Schistosomiasis is now endemic in over 70 countries world-wide, and affects over 200 million people (Doumenge *et al.* 1987). Water resource developments such as irrigation extend the available habitat for aquatic weeds and the snail vectors of schistosomiasis and thus increase the opportunity for human contact with the disease parasites. The density and reproduction of snail populations are strongly associated with aquatic weeds (Dawood *et al.* 1965; Dazo *et sl.* 1966; van Schayck 1985; 1986; Madsen *et al.* 1988). In canal irrigation systems, the most important sites for the transmission of schistosomiasis are usually earthen tertiary or quaternary canals where there is often abundant vegetation, snail densities are high and human contact with water is greatest (Madsen *et al.* 1988).

The costs of attempts to control the diseases listed in Table 3.4 are high and impose a burden on the economies of many tropical and sub-tropical countries (Coates and Redding-Coates 1981). Furthermore, the magnitude of the effect on populations in terms of the reduction in workforce, loss of work hours and so on can hardly be estimated, not to mention the more compassionate considerations of these debilitating diseases.

3.7.6 Competition with crops

Heavy weed infestation is one of the principal causes of low grain yield in rice (de Datta and Bernasor 1973). Weeds adversely affect germination, interfere with the establishment of seedlings, and later compete with the crop for nutrients, thereby reducing crop yields (Madrid *et al.* 1972; Soemartano 1979; Assemat *et al.* 1981; Majid and Akhtar Jahan 1984). In the context of these guidelines it is important to recognise the potential for irrigation and drainage systems to provide a source of crop weeds and a means for propagules (reproductive parts) to be transported from the channels to the fields, especially in the case of crops such as rice.

3.8 Recording the condition of irrigation and drainage channels

This chapter has shown the importance of weed communities and the successional cycle. Effective weed management requires a system for describing the weed-related condition of a channel as it varies with time.

The condition of a canal or drain at a particular time depends on the degree of structural and dimensional deterioration, and the degree of weed infestation and siltation. The condition worsens over time, but it may be improved by maintenance operations. Common engineering practice is to use relative grades to describe the condition of a channel e.g. good/fair/poor/bad. This works well in annual surveys of the need for maintenance. It is a subjective system however which would be difficult to use at different times of the year when irrigation requirements are low and a poorer channel condition can be tolerated.

We suggest the use of the simple descriptions of the weed communities supplemented by a note on the presence/absence of specific problem weed species. Our experience with operations and maintenance staff in Zimbabwe and Kenya has satisfied us that they could use this system satisfactorily to monitor and record the actual condition of each channel on a regular basis (e.g. monthly).

Weed clearance improves the hydraulic performance of a channel, recovering the weed-related condition from a 'poorer' to a 'better' state by returning it from a later to an earlier successional stage. The extent of the recovery is dependent on the degree of weed clearance. Dredging (or de-silting) operations, for instance, remove weeds and their root material as well as silt, thereby returning the channel to an earlier stage of succession than other weed clearance operations.

Following weed clearance, the successional process recommences. The rate at which it proceeds depends on the channel type, the persistence of the remaining vegetation and the potential for invasion and colonisation by new weeds as well as the frequency of weed clearance operations.

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Plate 3.1 Examples of the four aquatici weed types: (a) submerged (*Potamogeton sp.*), floating-leaved (rooted to the channel bottom) (*Aponogeton sp.*), (c) free-floating (*Azolla sp.*), and (d) broad-leaved emergent weeds (*Polygonum sp.*).

Plate 3.2 Cycle of aquatic weed growth in an irrigation channel following maintenance (see Figure 3.3)

Plate 3.2 Cycle of aquatic weed growth in an irrigation channel following maintenance (see Figure 3.3)