CHAPTER 4

GUIDELINES ON IDENTIFICATION OF FEASIBLE CONTROL METHODS

4.1 Introduction

Textbooks on aquatic weed control typically illustrate the wide range of techniques which are available for the management of aquatic weeds in channels systems (e.g. Pieterse & Murphy 1990; Riemer 1984). These focus on mechanical and chemical methods with some consideration of manual and biological techniques. In reality, the methods which are used for a particular scheme tend to be based on tradition, i.e. what has been used in the past, and on opportunity, e.g. the availability of a particular type of machine and the funding to purchase or hire it.

In many irrigation schemes in developing countries manual control is the traditional means of control and hence forms an important component if not the most important in maintaining the system. Information on the different manual techniques is therefore essential and this chapter includes a focus on this set of techniques. This information can be used as a basis for either a change to a different form or forms of manual control, or an adaptation of existing tools, e.g. providing longer handles or including the use of a secondary tool such as a rake.

Where the opportunity arises either to acquire a machine or to bid for funding, it is necessary to consider the advantages and disadvantages of the various types of mechanical devices which are available. The main different types of machines which could be used in irrigation and drainage channels are described and information provided on the advantages and disadvantages associated with them.

Consideration is given to the use of herbicides, environmental techniques and the potential of biological control agents.

An aquatic plant management strategy should be flexible and able to deal with different types of weeds in the various different types of channels. In a particular situation, the combination of one or two methods may be appropriate. for example, a strategy might be based on:

a. Use of an hydraulic excavator with a weed cutting bucket with a reach sufficient to deal with the majority of the arterial channels and with the potential for dealing with one-off situations in other parts of the system.

b. Regular use of manual clearance of weeds based on a range of tools. These tools would be used for specific tasks, e.g. chain scythe for submerged vegetation removal in large channels and rakes for removal of submerged vegetation in smaller channels. These tools should be such that there is no need for the operative to enter the water.

c. Occasional control using a herbicide. A herbicide should only be used to deal with one-off problems which could be site or species related. Precautions would need to be taken to ensure that only the weeds were damaged. Such usage should include a full programme for that site or species to ensure lasting control, i.e. a single application is unlikely to be effective.

d. Planting trees along carefully chosen channels can effectively limit aquatic plant growth through shading and act as a cost efficient means of weed control. Such trees can also provide a timber crop if only for fuel when selectively cropped.

e. Identification of the different types of weed species with a consensus being reached on which weeds need the most effort putting in to control them. Attention needs to be drawn to other species which although not known from a given irrigation system, might colonise it and need immediate attention.

f. Aquatic plant management should be seen as:

  - a joint responsibility between authority and farming community
  - an on-going maintenance requirement
  - different from weed control in the field or crop situation in that aquatic vegetation is important in the channel for stabilising banks, sheltering and providing food for fish and providing forage for livestock.

Figure 4.1 provides a series of flow charts to aid the selection of appropriate aquatic weed control measures.

4.2 Manual control

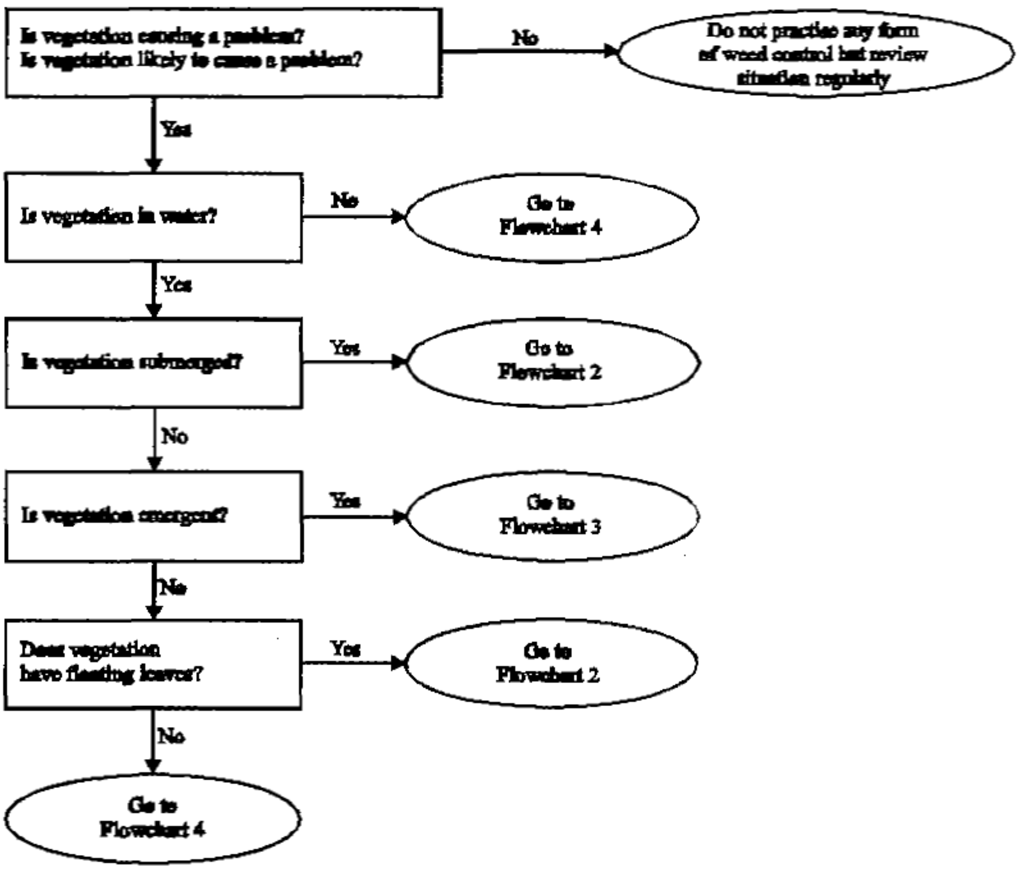
4.2.1 Introduction

Manual techniques include pulling, raking and cutting and until recently these were the only means of weed control. Today they remain important in many parts of the world and especially in those countries where labour is readily available and cheap. However, success is variable due to such factors as the extent of weed removed. For

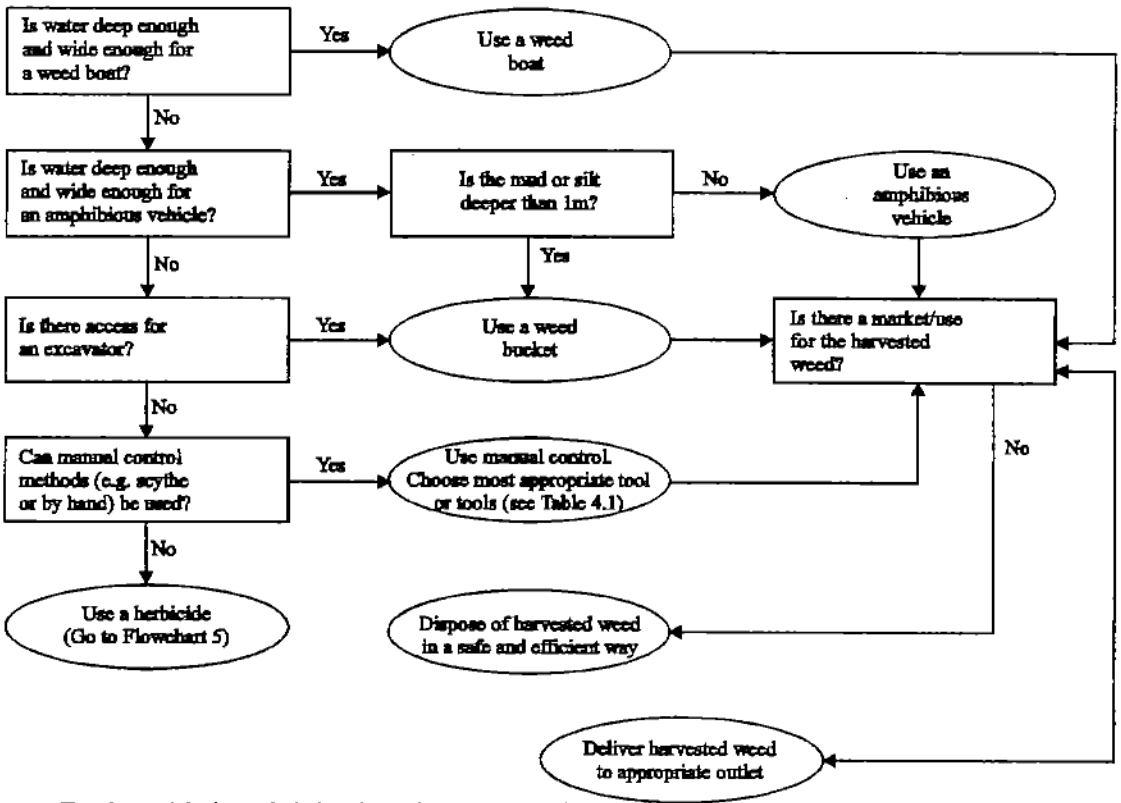
Figure 4.1. Flowcharts to aid the selection of the most appropriate method of aquatic weed control

Flowchart 6 presents the decision route where herbicides are the preferred option

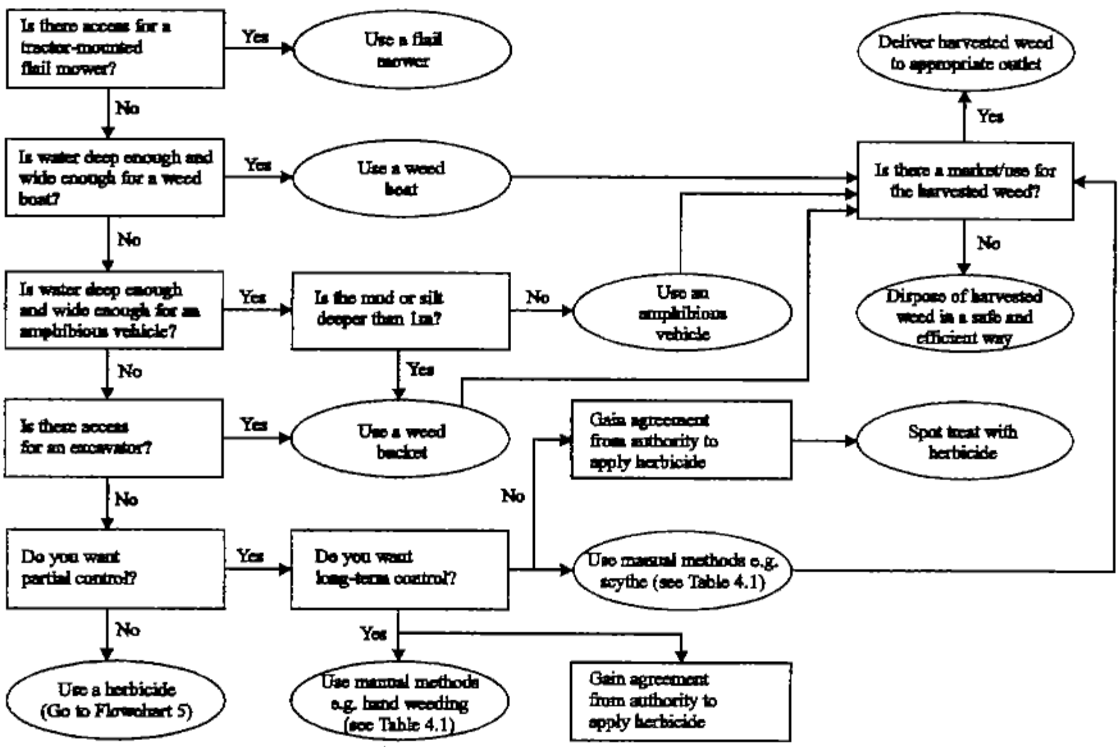
Flowchart 1. Selection of appropriate method



Flowchart 2. Selection method of weed control for submerged and floating weeds

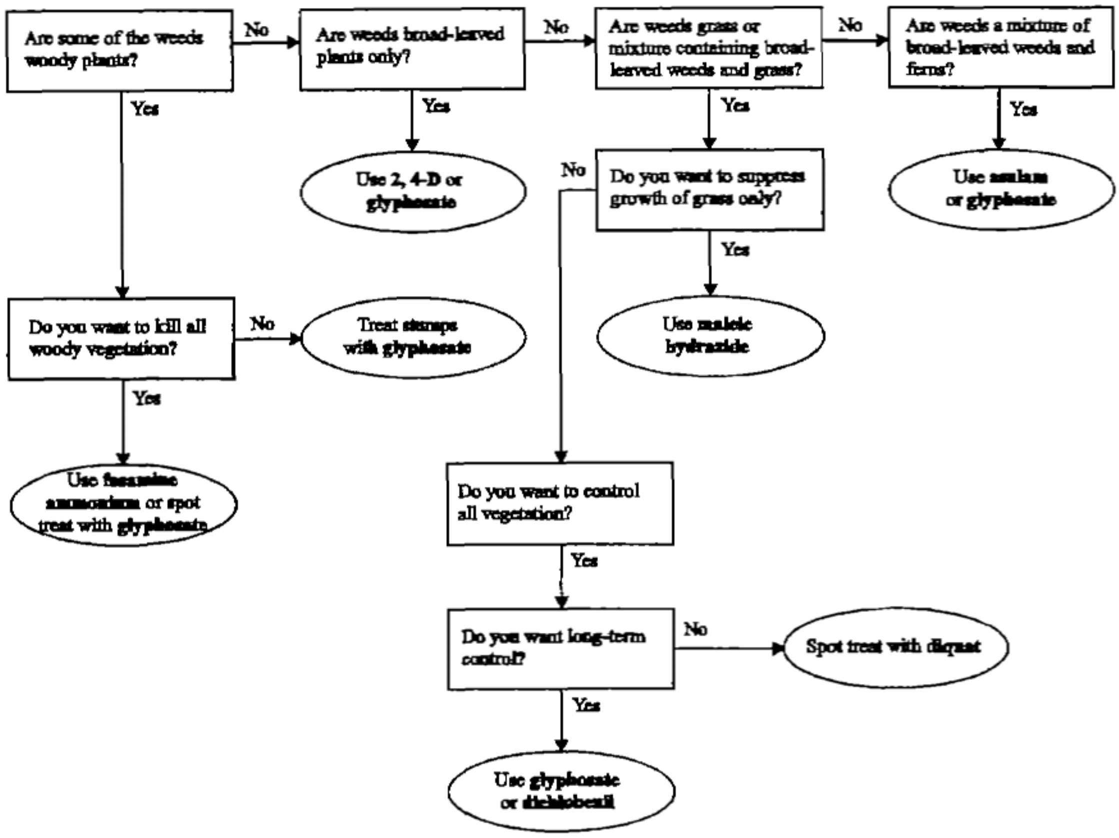


Flowchart 3. Selection method of weed control for emergent weeds

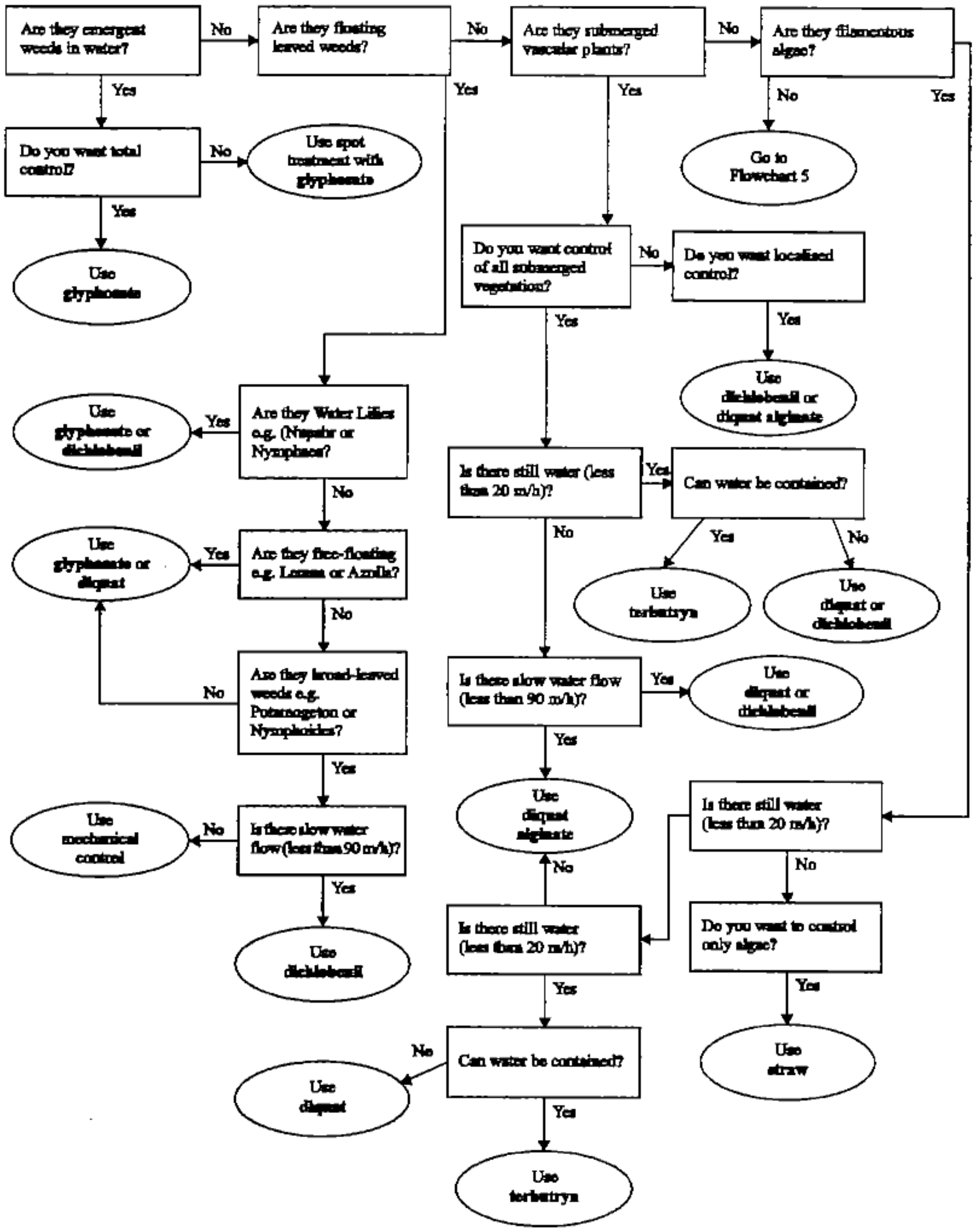


Flowchart 4. Selection of method of weed control for bankside weeds

NB. Always ensure that permission/license has been granted for use of a herbicide. Always follow the instructions on the manufacturers label.



Flowchart 5. Selection of most appropriate herbicide for aquatic weeds. NB Always ensure that permission/licence has been granted for use of a herbicide. Always follow the instructions on the manufacturer's label



example, in India 50% of manual treatments of the free-floating *Eichhornia crassipes* achieved only partial success, with 25% total success and 25% failure in the remainder of the treatments (Varshney and Singh 1976). In programmes for *Salvinia* clearance it was essential to have follow-up treatment in order to achieve lasting control, up to three manual cuts being reported for some channels. Without this, complete reinfestation can occur. Examples of successful or partially successful (65 to 90%) treatments have been reported for *Nelumbo nucifera*, *Pistia stratiotes*, *Nymphaea stellata*, and *Hydrilla verticillata* (Wade, 1990).

The hand-held implements currently in use for controlling weeds in irrigation and drainage systems are mostly modified forms of traditional tools used for agricultural purposes. In most cases they have been developed by the operators themselves to meet a local need. As a result, a range of tools, differing widely in their shape and performance has evolved and has until recently been handed down from generation to generation with little alteration.

Plate 4.1 illustrates some of the manual techniques which can be used in irrigation and drainage channels. Table 6.1 provides a summary of the productivity of labour which has been achieved using different hand tools for aquatic weed control in channels.

4.2.2 Manual tools

There is a wide range of hand-held tools for cutting and clearing aquatic and bankside weeds (Plate 2.1). The long-handled nature of these tools is not only to provide a good reach into the wider channel, but to prevent the worker from having to enter the water. These tools include:

4.2.2.1 Chain knives and chain scythe

The chain scythe is made up of 5-10 scythe blades, depending upon the width of the watercourse, each 50 cm long. The blades are bolted together loosely so that they can make hinge-like movements. The bolts are secured by split pins. Each of the two outer blades has an eye for fastening a rope. Variations on this these are simple a heavy chain or cable or an A-frame.

The construction of the chain scythe allows it to operate close and parallel to the bottom of the watercourse cutting through and uprooting submerged and floating species of plants. The gang operating the chain scythe consists of three labourers: two handle the scythe, one on each bank of the watercourse, while the third person collects the cut plant material accumulating at a barrier, culvert or other obstruction. The scythe operators lower the tool obliquely across the watercourse into the water at the downstream end of the reach so that the cutting edges of the blades point in the direction they are going to work. They operate the tool by pulling at the ropes in turn while walking slowly forwards, so zig-zagging the chain scythe over the bottom. This tool is very effective against such plants as *Potamogeton* species and young shoots of *Phragmites* and *Typha* (Druijff, 1979).

It is not possible to operate this tool using manpower under all conditions, and the following should be complied with:

- the cross-section of the watercourse must be more or less curved without sharp angles so that the chain scythe can touch the bed at all points
- the banks must be clear of trees, posts, barbed wire and other obstructions
- abundant weed growth along the banks must be removed before using this tool
- stones, pieces of metal and other such items should be removed from the channel in order to avoid premature blunting of the edges of the scythe
- the maximum surface width of a channel which can be cut using a chain scythe is about 6m.
- the water depth should be no less than 50 cm so that there is enough water to brace the weeds when they are being cut.

Some 500 m per hour actual working time can be cleared with this tool. Assuming a working day of eight hours, two of which are spent on sharpening and maintenance and another two on rest and moving from one location to the next, the daily production figure will be some 2,000 m of watercourse for three labourers (Druiff 1979).

Where there is substantial weed growth, in addition to the two workers pulling the chain scythe, four to five more will be needed to follow on, pulling out the cut weeds onto the banks using long-handled forks.

4.2.2.2 Scythe

With a sharp horizontal 0.6 to 1.0 m long blade and its long wooden handle set at roughly right angles to the blade, the scythe is perhaps one of the most successful hand-held tools. Its handle has been modified a little but it is virtually the same tool as used in Europe for centuries to cut hay. Some skill is required to operate it, but once its use has been mastered, it is a very efficient means of cutting submerged weeds and can also be used for the grass, sedges and reeds on the bank. In skilled hands it gives a closer cut than with mechanical cutters and results in slower regrowth. It also enables the operative to be selective in the weeds removed.

4.2.2.3 Clearing scythe

This tool consists of a sturdy blade on a curved steel handle with adjustable grips. A short curved knife is attached to the back of the handle near the blade to enable heavy woody stems to be cut. The tool is operated with short jerks unlike an ordinary scythe which is operated in a long flowing movement. It is ideal for cutting weeds growing along the banks of a watercourse close to the water's edge such as species of*Typha*, *Phragmites* and *Cyperus*. A skilled worker can use the tool so that most of the cut weed is deposited on the banks.

This tool is too light to be used in neglected watercourses with heavy weed infestation. Some skill is required to use the tool correctly and to avoid injuries to the legs.

The productivity in a well kept watercourse amounts to 150 m per effective working hour. Assuming a working day of eight hours of which two are spent in sharpening and maintenance and another two on rest and on moving from one location to the next, the daily production will be some 600 m on one side of a watercourse per person day (Druiff 1979).

4.2.2.4 Sickle, reed sickle and grass hook

Sickles and grass hooks with curved blades, and other tools used for cutting grass and weeds on dry land are also used in the water (Plate 2.1). Usually they are attached to longer handles so that the weeds on the bottom can be reached more easily. The labourer puts the sickle behind the stems, just above the roots. The weeds are severed from their roots by short jerky pulls.

4.2.2.5 Ditch bank knife or ditch bank spit knife

As its name suggests, the ditch bank knife consists of a sturdy knife, approximately 50 cm in length fixed on a long wooden handle 3 m in length. Around the shaft of the knife at the point where it is fixed to the wooden handle, a 2 m length of rope is fixed. The tool is operated by two individuals: one holds the handle and moves it up and down in such a way that the knife cuts the stems of the weeds while the second pulls the knife forward with the rope. It is particularly effective against non-woody weeds and in particular creeping plants such as *Ipomoea* species, which can begin raft formation. It can also be used to cut submerged weed. Due to its trailing nature and attached soil, the cut material does not easily flow downstream and a third person is needed to remove the plants with a digging fork.

The blade does not have to be as sharp as a scythe blade and if it is hammered out too thinly during maintenance, it will soon bend under the force exerted on it when passing through the ground.

4.2.2.6 Digging fork

The digging fork, most suited to cleaning operations along watercourses, has four to five heavy tines more or less at right angles to the handle. It is used to remove weeds cut loose by the ditch bank knife, and it can also be used in landing heavy floating aquatic weeds such as *Eichhornia crassipes*.

4.2.2.7 Slasher

A slasher is typically a long sword-like blade sometimes with a hand-grip at the end (Plate 4.1). The cutting end (15 cm) is bent at an angle to the main length of blade. The tool is swung to and fro to slash the vegetation just above ground level. It is particularly useful for cutting down bankside and marginal emergent vegetation. Cut vegetation should be removed from the channel and channel banks as it may propagate reducing the efficiency of the technique. A slasher can be used to good effect in a channel which has been dried out.

4.2.2.8 Rake and fork

Rakes and forks have been produced in which the handles and tines are longer than normal, and the tines are bent over. Such a type of fork is sometimes known as a crome. They are useful for removing cut plant material and filamentous algae. They are also used from the bank to drag out submerged plants without cutting but a proportion of stems always remain behind and although they may be damaged regrowth is usually rapid. Likewise, raking is unlikely to remove every bit of the plant materials, e.g. free-floating species, and regrowth will necessitate the procedure to be repeated. Forks have been used to lift floating plants of *Eichhornia crassipes* into barges but this is a slow operation and applicable only to small infestations or mopping up after using another form of weed control, e.g. mechanical cutting.

4.2.2.9 Hoe or long handled digging hoe

This tool looks similar to the traditional garden hoe but holes should be made to reduce resistance as it is pulled through the water. The hoe is fitted with an aluminium or wooden shaft 4 m in length. Shallow hoeing along the banks and beds of channels can be used to remove all the above ground material and some of the root or rhizome system (Plate 2.1). It is a selective technique which can be aimed at specific species and can be used in irrigation channels which have been dried out. If not undertaken with care, hoeing can draw earth from the banks into the centre of the channel thereby altering the channel profile. When hauling spoil onto the side of the channel, the handle is supported on the shoulder to enable more effort to be put into pulling the tool. The cutting edge of the hoe should be sharpened with a file. The connection between the socket and shaft should be checked. When there is some play in this, a wedge should be driven down the shaft near the socket.

4.2.2.10 Booms and barriers

Whilst a long-handled rake can be used effectively for clearing free-floating plants in narrow channels, for wide channels a barrier or floating boom may be preferable. This can be made from materials such as bamboo, a rope threaded through cork floats, a chain of barrels, or inflatable rubber units. The barrier needs to permit water to pass through it and to be able to conform to wave and wind action.

4.2.2.11 Netting

Small floating weeds, such as *Lemna* and *Azolla* species, can be skimmed from the surface of channels using drag-nets. The nets for manual operation, for example, from a hand rowed boat, are usually made of 3 mesh coir ropes.

4.2.3 Manual control in irrigation and drainage channels

There are essentially two approaches to manual weed control contracts:

a. periodic contracts in which third parties carry out weed control in a definite time period, e.g. one month;

b. lengthman contracts in which third parties are made responsible for the state of maintenance of a certain stretch throughout the period of one year (i.e. one complete growing season).

In both cases the cost or rates paid to the workers depend on such factors as top width of the channel, degree of weed infestation and length of channel to be managed. In a study of the Fayoum Water Management Project, Egypt, for an average sized canal with normal weed infestation, a daily productivity of 30 m per labourer, measured on both sides of the channel can be obtained. It was estimated that two periods of maintenance are necessary per year to guarantee a proper waterflow in the canal. Shortages in labour availability can be encountered in certain situations. These are usually related to the likelihood of contracting schistosomiasis or to higher wages being offered for work in the fields (Euroconsult 1994).

Manual weed control is widely practiced in the maintenance of irrigation and drainage channels. It has a number of advantages:

- very little foreign currency is needed to purchase the tools
- the tools do not require complex maintenance
- very little training of labourers is required
- a cheap form of control where labour is abundant
- operations can be easily contracted out once the management has gained some experience
- little need to upgrade inspection paths
- very selective and allows maximum control over the amount and type of weed removed
- usually produces predictable results when combined with follow-up treatment
- provides opportunity for utilisation of vegetation

The main disadvantage is that manual control can bring the operator into contact with water which is likely to be infested with schistosomiasis.

In order to maximise on this efficiency there are various questions which need to be asked:

- What is the basis for current manual control?
- Which type of vegetation does it deal with?
- Is it aimed at cutting or does it include removal?
- Is cut material put to any use? If not, why not?
- Could other tools be used to deal either with other types of weed (e.g. a rake to remove submerged vegetation) or more efficiently with weeds currently managed (e.g. a long handled scythe as opposed to a short handled scythe)?
- Are there health hazards and how can these be minimised?
- Are there labour supply constraints?

In order to answer these questions it is important to examine the range of tools currently used and consider their advantages and disadvantages. Table 4.1.

Table 4.1 Appropriate manual control methods for aquatic plants

Name of plant	Main method of spread	Recommended method	Alternative method
1. Free-floating & submerged unrooted			
Salvinia, Lemna, Eichhornia, and *Ceratophyllum*	Budding	Raking (short term only) Netting	Herbicide or mechanical
Filamentous algae	Cell division	Raking (short term only)	Use of straw[1]
2. Submerged, rooted			
Egeria, Hydrilla & *Potamogeton*	Roots, stem fragments & occasionally seeds	Cutting and hoeing with harvesting using booms/barriers	Raking, herbicide or mechanical
3. Floating leaved (rooted on bottom)			
Nymphaea & *Nymphoides*	Rhizomes & rhizome fragments	Scything, cutting (e.g. scything) below water level	Mechanical cutting or herbicide

4.2.4 Selecting the best tools

Manual control can be broadly divided into digging out or cutting. Digging out plants complete with their roots or rhizomes is a very effective method for controlling emergent species at the water's edge. Cutting is much quicker than digging, but less effective, because the roots remain and it will need to be repeated more often. Cutting the emergent plants at the base of the stems can be done using hand tools or, in deeper water, using a chain scythe. Where possible emergent plants should be cut below the water surface to maximise damage. alternatively the channel could be flooded after cutting in order to achieve the same effect.

Raking can provide useful control of most free-floating and surface plants such as *Salvinia* and filamentous algae using a long-handled rake or boom.

When choosing tools for manual control and devising a maintenance strategy it is important to consider the following:

- The work force should not have to enter the water in order to carry out their tasks. If this is the case the wrong tools are being used. There is often a risk of schistosomiasis in irrigation systems as well as other water borne diseases.
- The bankside habitat can harbour animals such as snakes and the cutting pattern should be such that this problem is minimised.
- The work force should respect the water in the channels and not foul them. It might be used for drinking and washing purposes.

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[1]for explanation of this method, see section 4.5

Each different method has its own advantages and disadvantages and these need to be considered in relation to the irrigation and, or drainage channels under consideration. Modifications to a particular tool might be appropriate to make it better fitted to dealing with a particular species or channel type.

4.2.5 The importance of channel type

Manual clearance will vary from one channel type to another. These can be divided into four main types:

a. Main channels with a significant flow. The principle advantage in this type of channel is that having cut the weed it can be carried downstream by the flow and collected by raking at an appropriate point either using a boom or a fixed control structure. The latter are typically serviced by a track or road where material needs to be transported away.

   Larger channels pose problems due to width and depth. A useful tool to consider is the chain scythe which is operated from both sides of the channel and is particularly suitable for submerged and rooted floating vegetation. Given that main channels should not support significant emergent growth, such a tool could deal with most of this type of channel.

   When dealing with free-floating vegetation it is important to be thorough in removing the plant material. Typically they reproduce from an individual plant, the population doubling each time it reproduces. The removal programme should be started upstream working down the channel to minimise reinfection.

   The task of dealing with submerged and floating weeds can be reduced by mowing the vegetation on the banks to facilitate access prior to maintenance.

b. Medium sized channels can support the full range of plant growth and whilst a chain scythe might be appropriate in certain channels especially where there is significant flow, in others long handled tools are likely to be more efficient. Submerged and floating vegetation are the more usual types of weed and it is recommended that effort is made to keep these weeds under control. If they are left to develop mats growing out from the margins or as islands in the middle of the channel, they will be colonised by emergent species and the problem of maintenance will increase dramatically.

   Where emergent vegetation has achieved problem levels, a team approach is necessary to rake out, or cut and rake out the leaf and root or rhizome material. The latter are often extensive and difficult to break up.

   As with main channels thorough removal of free-floating vegetation is essential. Mowing the vegetation on the banks to facilitate access prior to maintenance, can be very helpful.

c. A range of hand held tools is available for smaller channels which are in water perennially (see 4.2.2 Manual tools) and it is likely that more than one tool will be needed to satisfactorily deal with the range of vegetation encountered.

   A technique for dealing with emergent vegetation is to drop the water level in the channel and to cut the plants low enough so that when the water is allowed to return to its normal level the cut stems are below the surface. This is known to severely inhibit if not prevent regrowth in some species, e.g. *Typha* species. The same might be true for other species.

   The smaller channels are typically the responsibility of the farmers. Working together on each others channels can be more efficient and safer.

d. In the smaller channels which occasionally dry out, aquatic plants are rapidly damaged when the water is drained out of a channel. In order to maximise the damage make sure that sluices and other such structures do not leak. On the other hand be careful that drying out does not cause the bank to crack and lose water on refilling.

In addition to the options available in (c), it can be advantageous to wait until the channel is dry and to remove the vegetation at this stage, e.g. using a hoe. The channel is easier to work in and because of the absence of water the vegetation can be lighter to work with. Submerged and floating species will rapidly dry and decompose but remember that for many submerged species and for rooted floating species, the root and rhizome systems remain viable. If these plants have become a serious problem, clearance when in water might be preferable in that the roots and rhizomes can be more easily removed.

Channels which can be allowed to dry out also offer the potential for burning the unwanted vegetation and hence removing the bulk of the material. This is particularly valuable for emergent vegetation and can also reduce the viability of propagules. Piling up the material and burning in a light to moderate wind is the most effective means of burning, generating sufficient heat to kill the seeds of most species. Remember however that the ash which remains will act as a fertiliser for the plant growth once the channel has been refilled and a bloom of algae or submerged vegetation is typical. When using fire it is necessary to take precautions to limit damage to the treatment area. Comply with local laws and guidelines and use breaks of sufficient width to stop uncontrolled spread.

Burning is not necessarily a good idea and depends very much on the species being managed. Some, for example, *Phragmites australis*, will grow more densely and vigorously after burning than before due to the breaking of dormancy in buds or an increase in the amount of available light due to removal of accumulated leaf litter.

Do not rely on burning in case the weather prevents the vegetation drying out sufficiently for it to burn thoroughly.

4.2.6 Maintenance and training

Once a maintenance strategy has been established including decisions on which tools to use, a check needs to be undertaken to ensure that:

- the workforce is trained in the efficient and safe use of any new tools;
- the necessary equipment is available in order to maintain the tools, e.g. new blades and sharpening equipment;
- replacement tools are available in case of irreparable damage to or loss of those in current use.

Maximum advantage of manual control is only achieved when the workforce is familiar with the different types of vegetation in the channel. This could range from knowledge of species which are notoriously difficult to cut or rake, to those which are advantageous, e.g. important for bank stabilisation or useful as a food source. Such knowledge can be gained gradually or taught in a more structured manner. Where it is learned gradually, it is necessary to make sure that the knowledge is passed through the whole workforce and also on to new staff as they arrive. Check that everyone is using the same names for the various species which have been identified and record this information including observations on distribution and the seriousness of the species as a weed. This helps to identify problems as they develop, rather than having to wait until they are becoming insurmountable.

If a workforce is to be taught in a more structured manner make sure that there is the necessary support, e.g. an identification aid/manual and an explanation as to why a knowledge of the weeds can be so valuable. An effective aid is a collection of plants either as fresh material collected immediately before the training session, or as dried specimens put on to card and kept as a reference collection. The latter can be labeled up and, if the opportunity arises, shown to a botanist to check. Such dried specimens on card can be photocopied and made up into a field guide. Again, check that everyone is using the same names for the various species which have been identified and record this information including observations on distribution and the seriousness of the species.

4.2.7 Appraising performance

Success with a revised maintenance programme will not be immediate especially where a new tool or tools are involved. The workforce will need time to adjust to new techniques and to learn about the different weed species. Nevertheless it is necessary to appraise the success of the programme against the hydraulic objectives established.

It might be necessary to try out different ways of working with a new tool though this is best undertaken in the training period prior to implementing the programme.

4.2.8 Poisonous plants

Livestock usually avoid poisonous plants because they tend to be unpalatable. Cutting, and also dredging and herbicide treatments, can increase the danger to livestock in three ways:

a. the plants and particularly the roots can be exposed and moved up the bank so that they are more accessible to animals;

b. the cut vegetation may be mixed with palatable species so that poisonous material is eaten accidentally;

c. several of the more poisonous species become more palatable after being cut or sprayed but can remain poisonous as long as dead plant material remains intact.

Use local knowledge to identify if poisonous plants are present in or along the banks of channels and take precautions where necessary to fence off or remove the cut or treated material containing the poisonous plants.

4.3 Mechanical control

The diversity of machines devised to cut, shred, crush, suck or roll aquatic weeds is wide. This assemblage of machines can be usefully divided into two groups:

1) those aimed at cutting and/or otherwise removing solely the aquatic weeds;

2) machines which have other functions apart from weed cutting and/or removal, for example, dredgers.

Some of these machines are water-based on boats and barges, others work from the bank and shore, mounted on tractors or as purpose built machinery. Useful reviews of machines are provided by Gopal (1987) and Wade (1990).

Flowcharts 2 and 3 (Figure 4.1) assist in making a choice of appropriate mechanical methods.

4.3.1 Cutting, chopping, shredding and harvesting

4.3.1.1 Floating machines

Floating machines are used mainly to manage floating and submerged weeds and early devices were simply rakes or other pieces of farm machinery, weighted to keep them from riding up over the weed beds whilst dragged behind boats. The scratching and scraping action dislodged and broke off the weeds. Smaller weed-cutting boats were developed in Europe and North America which used a V-shaped knife with either a serrated or a straight edge pulled along the channel bottom behind the boat. The blades dulled easily and required an even bed devoid of solid obstacles, such as tree branches and rocks. The design of these weed cutting boats soon advanced to make use of reciprocating cutter (or mower) bars, initially horizontal straight bars1 to 2 m long, lowered and fixed to cut at a required depth. In some devices the bar could also work at an angle to and above the water surface cutting emergent vegetation along lower parts of the bank. U-, K-, and inverted T-shaped cutter bars were the next step forward in design, coupled with hydraulic control of the depth and angle of the cutter bar in the water.

The 1 to 2 m swath cutter bars of the smaller boats were increased to 3 to 5 m to fit onto barges, improving their capacity for cutting weed. A wide variety of models based on this design has been marketed. The basic design is a flat, self-propelled barge with a steel hull capable of working in very shallow water. Propulsion is typically by paddle wheels, which increase manoeuvrability and give a shallower draft. Two hydraulically-controlled arms extend from the front of the boat and a U-shaped reciprocating cutter bar is fastened between them.

The problems of propulsion of weed cutting boats have led to the exploration of alternative methods designed to overcome the problems of fouling by weeds. Different designs are needed for different types of water: independent hydraulically-driven paddles are ideal for small craft in larger drainage and irrigation channels with steel propellers being more appropriate in fast-flowing channels. The type of hull also depends upon the situation in which the boat is to be used. Steel is usually the preferred material, though moulded fibreglass is better for boats which have to be moved from one channel to another.

The early cutting, crushing, and shredding devices, both small and large, had a major drawback in that the treated plants remained in the water. Decomposition of the shredded material and a certain proportion of cut material caused undesirable effects by depressing concentrations of dissolved oxygen and producing unsightly heaps and obnoxious smells along the margins of water bodies. The breakdown of the organic material in the water also released inorganic nutrients which resulted in algal blooms and the increased growth of aquatic weeds. Cuttings of submerged plants could float in the water almost indefinitely and fragments of many species have the ability to root and regrow. The free-floating nature of the material meant that plants were able to move around or along a water body with the potential for new infestations. The fragment of plant from which regrowth can occur may be very small. In *Panicum repens* , for example, a one-node cutting 5 cm long is all that is necessary (Siregar and Soemarwoto 1976). Problems also arise from cut plants blocking screens, spillways, and channels.

Two solutions were explored to overcome these drawbacks: improving the effectiveness of the shredding and chopping, and harvesting the weeds. The former approach does not overcome the problems of deoxygenation and nutrient release. Harvesting, or removing the weed from the water body, has become an essential part of physical control. However, such harvesting is often time consuming and is usually the limiting factor in such mechanical control.

Techniques for harvesting the mass of cut weed range from manual raking using wind and current to concentrate the weed, through the application of dragline cranes, to sophisticated machinery with dewatering and baling facilities. Machines can also be fitted with fragment barriers. A typical system in an irrigation channel network involves one or more porous conveyor belts which pick up the weed from the water and transfer it to the bank of the channel, preferably at points where the cut and harvested material can be transported away. Further transportation of the cut weed is frequently necessary, to a site where the nuisance weed may be utilised and/or allowed to decompose. Smaller weed cutting boats now have the facility of changing the cutter bar for a rake (4 m in width), which collects the weeds together and using the hydraulic arms lifts and dumps loads of up to 300 kg of weed onto the bank. The nature of the bucket or rake depends on the species being harvested, for example, free-floating non-rooted plants require a fine mesh bucket.

The large quantities of unwanted water associated with harvested weeds are a major problem and presses can be used to reduce the weight of the load by 68 per cent and the volume by 16 per cent, although some organic matter is lost to the water (Bagnall 1980a,b).

The enormity of the task of weed control in heavily infested waters gives an immediate indication of the limitation of this method of weed control. Given a standing fresh weight crop of vegetation of 376 tonnes ha^{-1} and a modern weed harvesting operation which can remove approximately 1 ha of weed per hour, a crew attempting to control such an infestation from a water surface area of 160 ha would still be working four-five weeks later (Ramey 1982). The limitations are equally apparent with species capable of rapid regrowth. Culpepper and Decell (1978) calculated that harvesting systems with a disposal rate of 80 to 100 tonnes per hour were necessary for such species as the free-floating *Eichhornia crassipes* and the submerged *Hydrilla verticillata*. Although some come close, few harvesters appear able to achieve such a performance consistently.

Even if one assumes an efficient operation, there are a number of drawbacks which need to be appreciated in the use of floating machinery, particularly in the management of large water bodies.

1. Much of the machinery in use today has been developed with specific, often local, needs in mind which has produced a proliferation of different types of machines. Careful thought should be given as to the type/model of machine purchased.
2. The economic effectiveness of these machines is hard to estimate due to the complexity of the operation: cutting, harvesting, transportation, and dumping. The period during which the machine is out of action (down-time) also needs to be taken into consideration, as described in Chapters 7 and 8. The hidden advantages of nutrient removal are even more difficult to quantify. Comparisons with other treatments, e.g. herbicides, are therefore difficult.
3. Maintenance of machinery of this type is difficult, particularly for machines manufactured in one country and used in another, and often spare parts are costly.
4. Access to and along a channel may be difficult due to steepness of bank and presence of bridges. Long distances may need to be traveled, not solely to launch a weed cutting boat but also for the transportation of harvested weed away from the site.
5. Shallow waters present severe problems, in terms of the draught of the boat and with respect to the distances which have to be traveled in a large shallow water body.
6. The high cost of such management, exacerbated by the need for repeated treatment and the fact that the harvested weed has little or no value in many countries, may make the operation prohibitive.

On the other hand, there are a number of significant advantages of floating machinery.

1. The degree of selectivity which may be applied. This is of particular importance when vegetation needs to be left for example to benefit and maximise fish production
2. The removal of nutrients from the water
3. A reduction in the long term dependence upon foreign currency as harvesting reduces the need to purchase herbicides
4. Compatibility with terrestrial crops growing near the water body, not necessarily achievable with machines operating from the bank and herbicides

5. The potential for quick and predictable removal of weeds from specified areas
6. The production of useful materials, e.g. green manure and animal feeds.

4.3.1.2 Machines operating from the bank

A range of cutting mechanisms has been developed which operate from the bank of a channel, drain or river (Plate 2.2). Several devices have been developed for use with dragline excavators and the hydraulic attachments available on modern tractors and excavators. The reach of such machinery varies: a tractor-mounted flail mower has a reach of up to 7.24 m; a weed cutting bucket mounted on a hydraulic excavator 11 m and a weed cutting bucket on a dragline 18 m. The machine may be fitted with a weed cutting bucket or a dredging bucket. The most widely used device is the weed cutting bucket, considered to be the most important development in recent years in irrigation and drainage channel maintenance. The bucket is attached to the hydraulic jib of a tractor or excavator and, in operation, the lower edge has a cutter bar which may range from 2 to 4 m in length. The bucket is lowered parallel to the substrate surface and pulled towards the excavator by the jib, cutting the weeds on the way. The bucket is able to cut weeds on the banks and the bed of the watercourse and, given a sufficient reach, both banks can be cut in one sweep. The cut weeds collect in the bucket which does not retain the water and are lifted out and dumped on the bank or in a truck. Depending on the skill of the operator, the bucket can cut above or slightly below the sediment/silt. The main problems with this technique are trees and other similar obstructions which reduce accessibility of the weeds and watercourse from the bank. Additionally, there is a disruption of land use especially where regular maintenance is required. This area of land or the maintenance path is 1.7 to 2 m wide although some machinery is available requiring paths only 1.2 to 1.5 m wide.

The availability of continuous access along the bank top is an important requirement, which may inhibit the use of these methods on many existing channels, for example, channels on the Chisumbanje estate.

A weed rake operated from the dragline excavator is also a popular device, more robust than the weed-cutting bucket.

A range of other equipment has been specifically designed for weed removal from the bank, for the removal of cut weed and especially filamentous algae, and for use on screens at pumping stations. Weed cleared from ditches or canals by weed buckets mounted on a bankside excavator may also be dumped straight onto the bank or onto barges. In flowing waters cut weed is usually allowed to drift downstream, for collection by boom systems.

Rotary, reciprocating and flail cutters provide an important range of machines for cutting emergent and bankside vegetation. A wide variety of small self-propelled pedestrian and ride-on cutters can be used on slopes with gradient less than 2:1 although Allen motor scythes can work across steeper gradients under suitable conditions. Operation of this type of equipment is difficult and tiring and, where access is available, tractor-mounted cutters provide a useful alternative. Such devices are usually operated from a tractor or excavator attached to hydraulic arms. A choice exists between lightweight and heavy duty flails with cutting heads in the region of 1.3 m wide and long reach arms. Adjusting the cutting depth on rotary cutters is difficult and can cause damage to the sward. Damage to the machinery can result from stones and other hard objects such as wire and string which can add considerably to down-time.

The National College of Agricultural Engineering (NCAE), England, undertook a review of existing machinery for the management of drainage channels (Murfitt and Haslam 1981) and indicated that reciprocating drum and disc mowers could be used in any section within the water channel. The rotary devices, although needing higher power, are very much more robust than the reciprocating cutters. Flail cutters/mowers are limited in use to the area above water. The NCAE also defined the design objectives for an ideal machine, which should be robust, reliable, and able to operate in water. It should control rooted and non-rooted weeds at one pass without affecting the stability of the banks. It should have variable geometry to cater for a channel bed of 0.6 to 1.2 m and bank slopes of 30 to 45 degrees and remove the weeds to a stable position above 1.2 m up the bank . Price (1981) presented data on the characteristics of eight weed control machines related to these criteria, giving advantages and disadvantages. Two of the machines which came the nearest to satisfying the criteria, allowing for normal down-time and obstructions (e.g. culverts, side dykes) had an estimated output of approximately 2.4 km d^{-1} and 4.16 km d^{-1}.

Table 6.3 provides a summary of the productivity achieved using mechanical equipment for cutting aquatic weeds in channels.

4.3.2 Dredging

A major disadvantage of cutting and harvesting aquatic weeds, as a means of direct control, is that the underground material is left behind. This is particularly relevant for the submerged and rooted floating plants. More thorough control is achieved by dredging which removes both plant material, including much of the stem and leaf growth, and accumulated sediments. Such operations are usually undertaken from the bank using either dragline or hydraulic excavators (Plate 2.2). Tractor-mounted mud scoops are also produced, usually for use by individual land owners. The draglines have the advantage of a considerable reach whereas the hydraulic excavators may be used more easily to create a steep, uniform batter on the bank or banks, though recent engineering has combined both approaches. Dredging is particularly necessary in cases where sediment and, or organic material has accumulated in the system. and where other control measures would be ineffective.

The effectiveness of dredging depends upon a number of factors and, in particular, the depth of mud dredged from a water body and the depth of water after dredging.

The intervals between dredging are much longer than intervals between weed cutting, for example, and the degree of control is usually sufficient to negate the need for other control, e.g. herbicide application or cutting, for at least one full season. Further advantages accrue in that sediment removal extracts plant nutrients and where the depth of water increases, the amount of light penetrating to the bottom may be reduced.

The cost and time involved in dredging are considerable and there is also a problem with the disposal of the spoil/sediment - such sediments are not as useful as one might expect them to be. In the case of drainage channels and rivers, this waste material is usually dumped on the adjoining land and leveled. Fragments of vegetation, rhizomes, turions, and other propagules do tend to remain after management. Dredging, because it is expensive and slow, is commonly used only when a channel has deteriorated severely and other forms of maintenance are no longer effective, usually in conjunction with the removal of accumulated mud and other material.

Table 6.2 provides a summary of the productivity achieved using mechanical equipment for dredging irrigation and drainage channels.

4.3.3 Improving the efficiency of mechanical techniques

4.3.3.1 Timing

The season in which the control is effected is likely to alter the success of the operation. Plants with marked seasons for flowering and fruiting (e.g. the submerged weed *Najas* and the floating weed *Trapa*) or turion formation (e.g. the submerged weed *Hydrilla*) are best controlled before seeds or other types propagules are formed or shed. On the other hand, weed clearance on a regular basis can deplete the carbohydrate stores in perennating organs, effecting more lasting control. The prevailing weather conditions will dictate to some extent the time when control is undertaken especially when floating machines are used. The crop cycle also restricts the availability of labour and access into crops.

4.3.3.2 Improving the efficiency of existing machines and processes

More effort is needed to improve the efficiency of existing machines and processes and to reduce the cost of mechanical weed control. Every effort should be made to operate the machinery continuously and a good maintenance service with attendant resources is essential to this end. Particular attention should be focused on improving the efficiency of removing the plant material from the water body and the subsequent processing of harvested material. This may be reduced in volume and in weight by dewatering and through improvements in handling characteristics. The potential for the use of the cut material should be exploited.

The efficient use of any piece of machinery needs training and the acquisition of skill, a principle which extends to the maintenance of the machinery and reduction in down-time. More effort should be made to improve the training of personnel involved in such operations.

4.3.4 The development of new machines

The development of equipment for aquatic weed control lags behind the advances made in agricultural equipment, companies being inhibited by the restricted sales such machinery is likely to achieve. Nevertheless, new machines have been produced and interesting consideration has been given to the criteria which such plant should meet. In England, a National College of Agricultural Engineering study raised some fundamental ideas about the use of machines for controlling weed growth in drainage and irrigation channels from the banks (Murfitt and Haslam 1981). These were largely based on three premises.

1. The need to know the relationships between flow characteristics and the density, species composition, and physiological condition of the plants in the drainage channel. Mechanical control is seen not as a process of destruction but more as environmental management although such processes are very poorly understood.
2. The prediction of the reaction of the various species to cutting. This is only partially known and only for a few species.
3. Cutting is not necessarily the most effective means of controlling weed growth. It is based on agriculturally developed ideas and machines which themselves have developed to ensure the survival and regeneration of the cut crop. An improvement would be a machine or action which inhibited regeneration. This could include such actions as crushing and bruising especially roots or rhizomes, repeated chopping/cutting, drought, rolling, discing and damage due to alterations in the light regime.

4.4 Chemical control of aquatic weeds

4.4.1 Introduction

Herbicides can offer a cheap, effective, and rapid method of aquatic weed control. As a powerful tool in irrigation and drainage channel management, they require knowledge and understanding to be used safely and effectively. If misused, they can have side effects which may be harmful to aquatic organisms and, ultimately, to humans.

Most of the herbicides used in water bodies were developed originally for terrestrial use, so their basic behaviour and properties were already known before they were tested and adapted for aquatic use. Subsequent testing procedures have examined, in more detail, the toxicity to aquatic fauna, persistence and breakdown products in water and hydrosoil, effects on irrigated rate, susceptible weed species, and safety precautions required by the operator. Applications made without following these instructions can, at best, result in a poor level of weed control and, at worse, cause unnecessary damage to the target ecosystem. Even so, the user must decide the degree of weed control required in a particular body of water because overmanagement can be as harmful, in the long term, as undermanagement. The optimum level of control depends on the uses and priorities in each individual situation. A land drainage or irrigation channel may require total removal of aquatic weeds for the longest possible time, whereas in a channel also used as a fishery, reduction in emergent or floating weeds may be all that is necessary. Both of these extremes, and intermediate levels of control can be achieved by herbicides. The choice of the correct application method requires detailed knowledge of the capabilities and limitations of each herbicide. In many countries, government - or industry - sponsored training schemes are available which provide the user with both theoretical and practical experience of selecting and applying these herbicides.

Herbicides may have a direct toxic effect on non-target aquatic organisms or an indirect effect resulting, for example, from the removal of the target weeds. Laboratory-based toxicity tests often indicate greater toxicity than is found in the field. Thus they tend to err on the side of safety. Laboratory tests are followed by field experiments which can confirm laboratory results but may also show unpredicted toxic effects. By the time that the chemical receives official approval for aquatic use, the information available is such that direct toxic effects are unlikely to occur if the manufacturer's instructions are followed correctly. Some indirect effects are the inevitable result of the changes to the ecosystem caused by effective weed control. Thus, they are not limited to herbicides but can occur after any weed control operation. However, since herbicides can produce more thorough and, sometimes longer-lasting, control than other methods, the indirect effects can be more pronounced.

Several of the terms used to describe the behaviour and properties of herbicides cannot be defined absolutely because these properties vary under different conditions of use. For example, a herbicide may be termed 'selective' if it controls only a limited range of plant species. However, it may become 'non-selective' at higher rates of application.

The term 'active ingredient' (a.i.) refers to the concentration of herbicidally-active chemical within a formulation. It is expressed in terms of weight of active ingredient to volume (w/v: liquid formulations) or to weight (w/w: solid formulations), and may be shown either as grams per litre or percentage (e.g. the usual commercial formulation of glyphosate contains 360 g a.i. l^{-1} or 36 per cent w/v).

Herbicides may be selective (e.g. dalapon which controls grasses but not broad-leaved weeds) or non-selective (e.g. glyphosate which controls almost all green plants). Contact herbicides (e.g. diquat) kill only those parts of the plant on which they fall (usually, the foliage), but if sufficient damage is caused, the whole plant may die. Translocated herbicides (e.g. dichlobenil) are absorbed by one part of the plant but move within the plant and act on other tissues or growing points.

Persistent herbicides (e.g. fluridone) retain their activity in the soil or water for some time, usually measured in weeks or months. Non-persistent herbicides (e.g. glyphosate) act only when sprayed directly onto foliage and lose their phytotoxic activity very quickly on contact with soil or water. Some herbicides may show both characteristics; for example, diquat is non-persistent in an active form when sprayed onto terrestrial emergent plants. The droplets of chemical which miss the plant fall directly onto the soil and are rapidly and irreversibly absorbed onto soil particles, where they persist in non-phytotoxic form. In water, diquat molecules remain active in solution until they are absorbed by plant cells, or absorbed onto sediments. The term 'availance' is defined as the combination of residue concentration and period of residue persistence in the aquatic environment, which produces a phytotoxic effect on the target plants.

There are a number of herbicides suitable for the control of aquatic weeds varying widely in the range of species controlled, toxicity to fish, mammals and other life forms, persistence in the water and in the sediment, and the type of water in which the chemical will be effective. Some herbicides effect several plant families, i.e. many species, some effect only a limited group of species. There are also various ways of applying herbicides: spraying onto the foliage using a knapsack sprayer; distributing pellets into the water, and injecting into flowing water using an alginate formulation. Table 4.2 provides a useful summary of the range of herbicides and the types of plants they control. The label provided with the herbicide chosen for use will:

a. specify safety precautions to be observed by the operator;

b. state the interval of time to be observed between application and the use of treated water for irrigation of crops. Water intended for the irrigation of crops must not be treated with herbicides unless irrigation can be avoided for the period after treatment specified on the product label;

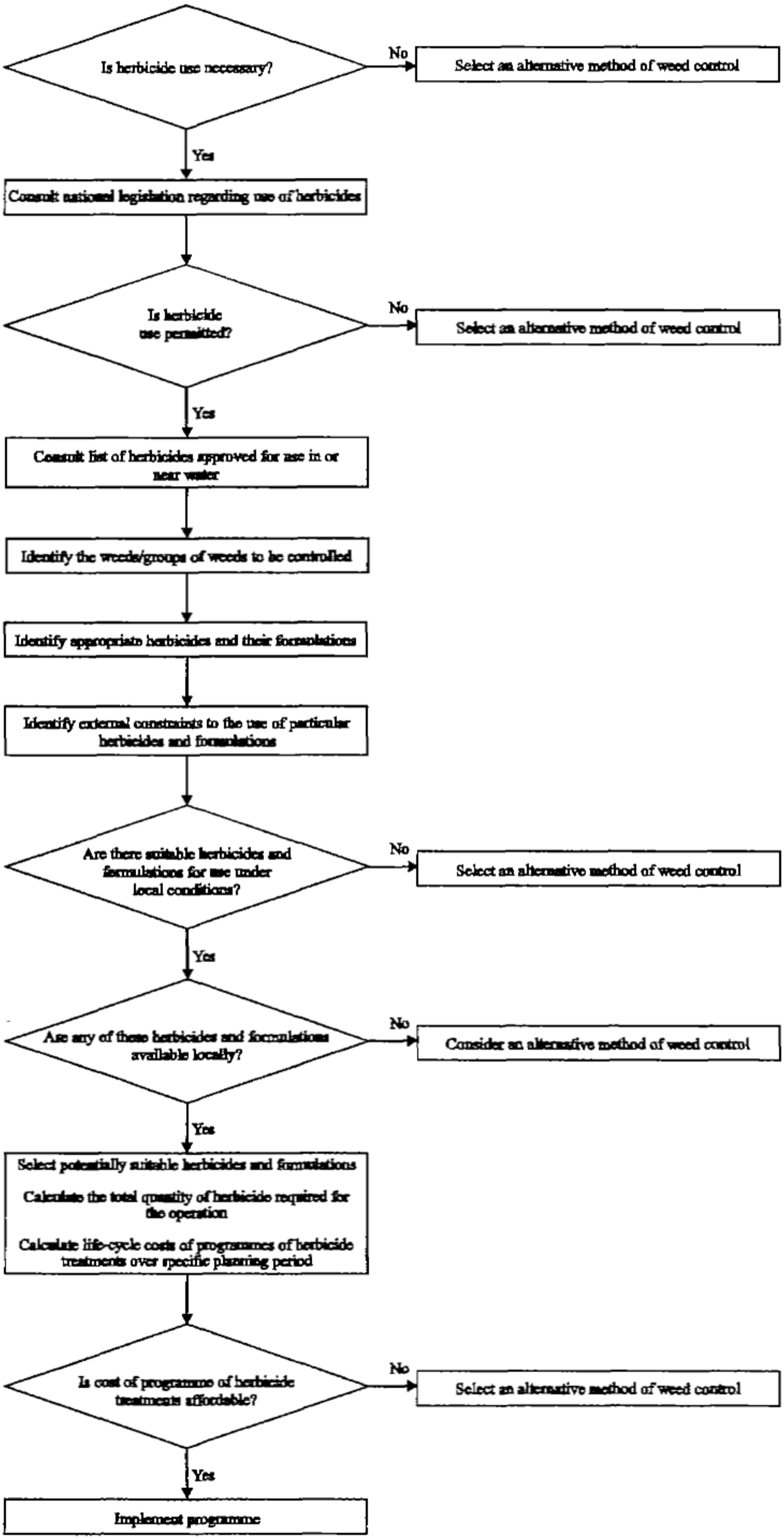
c. the range of species against which the chemical is effective;

d. provide detailed instructions on the use of the herbicide including the dosage to be used;

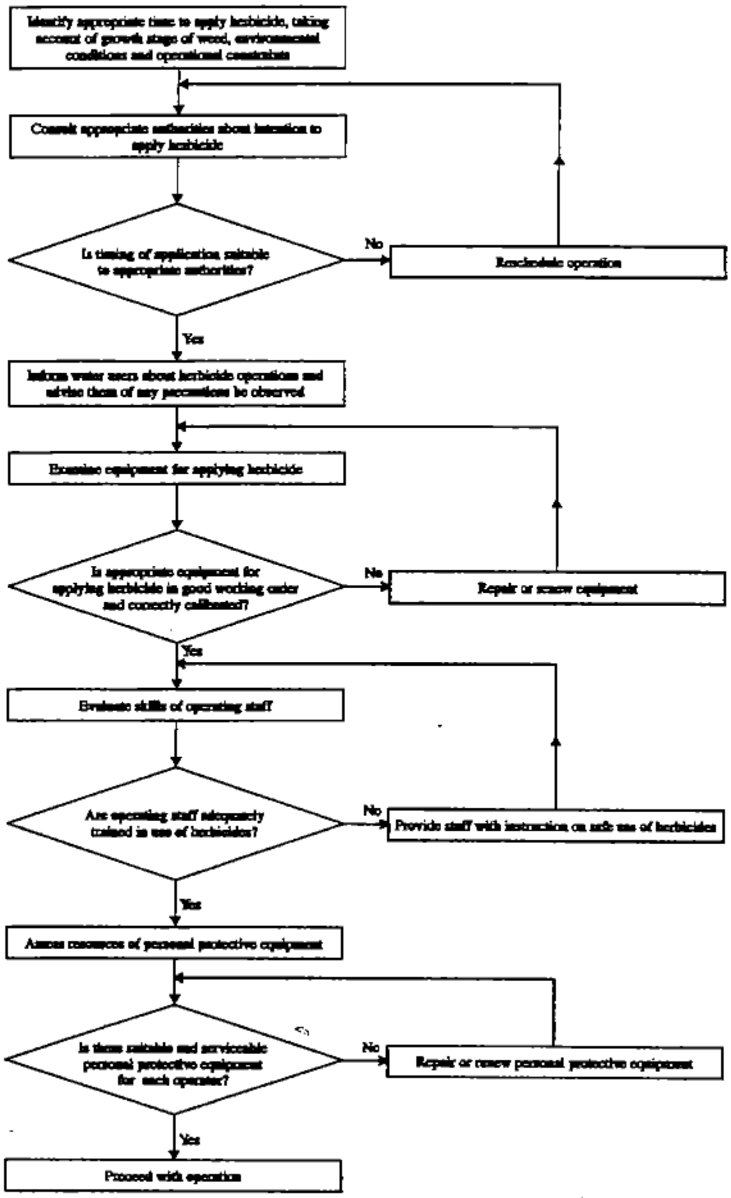
e. the conditions and means of formulation and application which should be used.

Flowcharts 1-5 in Figure 4.1 aid the decision whether or not to use a herbicide. Figure 4.2 provides flowcharts relating to the selection and preparation for use of herbicides.

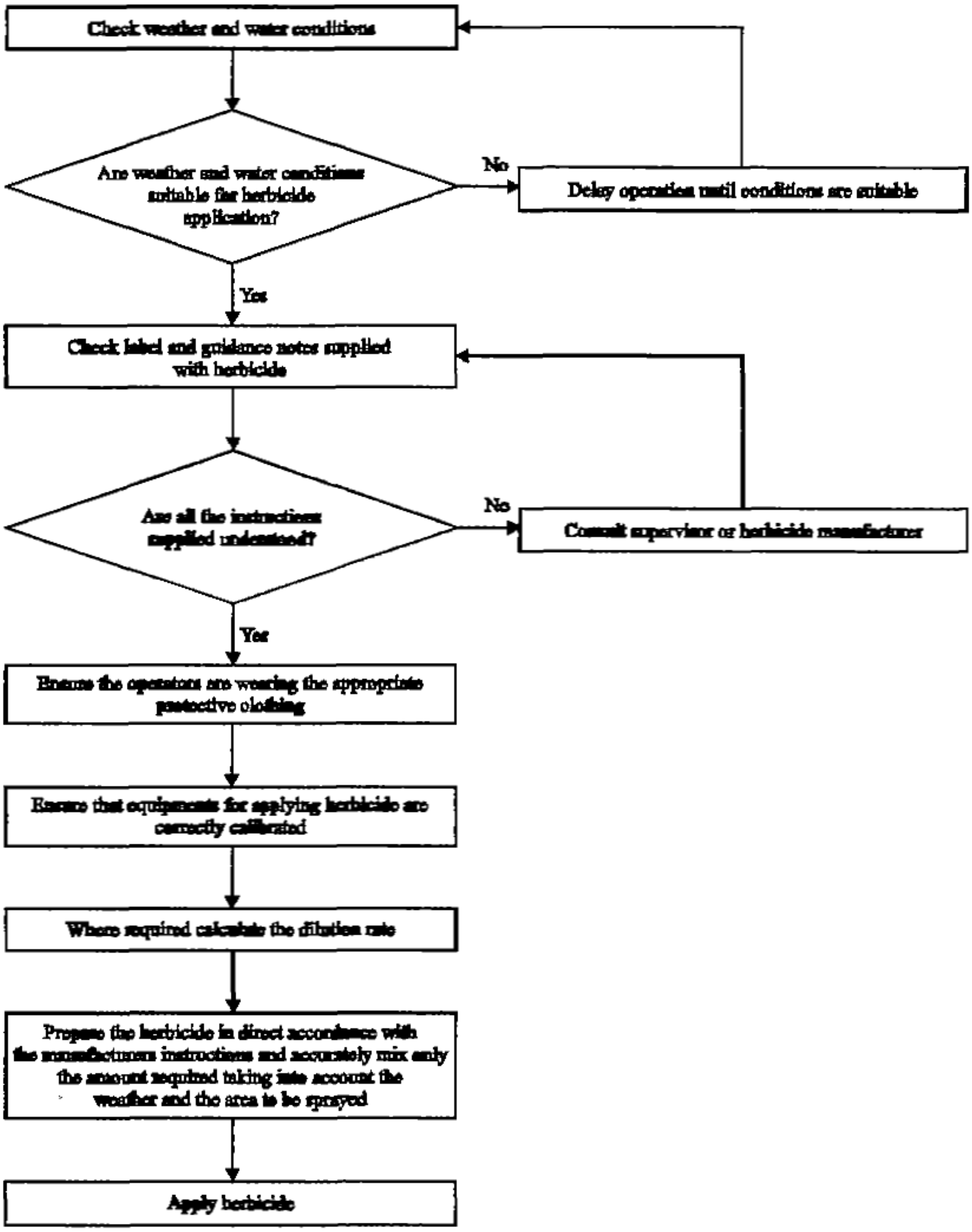
Figure 4.2. Flowcharts to aid the selection of and preparation for use of herbicides. Herbicides – Selection



Herbicides – Advance preparations for application



Herbicides – Preparations on day of application



4.5 Biological control

Biological control methods for managing aquatic weeds are based on the deliberate introduction or encouragement of a certain species which will restrict or prevent the growth of particular weeds. These species, or agents, can be herbivorous insects, mites, snails, fish, birds or mammals; disease agents such as fungi, or plants , e.g. trees, which shade and hence reduce aquatic plant growth.

Methods which could be considered for use in channels systems include:

a. herbivorous fish. Herbivorous fish (e.g. *Tilapia* and *Ctenopharyngodon idella*) have been proven to effectively control vegetation in irrigation and drainage channels. The grass carp (*Ctenopharyngodon idella*) does not normally breed outside its native China, nevertheless its introduction into a country or region would need to be considered carefully and appropriate steps taken to ensure approval of such a technique.

b. shading. Trees and floating aquatic plants can effectively provide shading such that other plant growth is inhibited. Such planting is best introduced early in the life of the scheme to enable maximum benefit. Trees need to be planted along those channels where shading will be most effective whilst minimising any impact on the crops (Plate 2.3). Wind direction can be used to minimise leaf accumulation in the channel. Such trees have other advantages including a harvest achieved through either selective cropping or fruit production, and shading for workers resting from their labours in the fields.

c. straw. The decomposition of straw in water has been found to release certain chemicals which stop algal growth and hence can prevent the build up of filamentous algae. The basis of the method is to put straw bails (either barley or wheat straw) into the water. These bails might inhibit flow in the channels and a stocking or sausage shape of packing the straw would be more appropriate. Although the technique has been used for a long time, its use on a planned basis for reliable algal control is only just being formulated.

There are significant advantages with biological control once it has been established, notably that the weed problem can be contained, e.g. using grass carp, with relatively little management input and hence cost. The disadvantage is that determining a biological control agent typically takes a long time and is not guaranteed to be successful. Herbivorous fish require a substantial investment in setting up and maintaining a breeding programme and the fish might be unsuccessful if they migrate out of the system or were caught by the local community as a food source. Using trees for shading is attractive but will take as long as is necessary for the trees to grow to maturity. More novel approaches, e.g. an introduced insect, need substantial research to ensure that sufficient damage will be done to control the weed but also to ensure that the introduced insect will not damage other plants, especially crops.

Biological control options are often regarded as the most environmentally friendly of control measures. This is not necessarily true. For example, overstocking with grass carp can lead to very turbid and eutrophic water, and trees established for shading can create problems through the accumulation of leaf litter in the channel.

4.6 Environmental and integrated control

Integrated control has been broadly defined as a management system that utilises all suitable techniques to reduce pest populations and maintain them at levels below those causing injury (van den Bosch *et al.* 1971). However, the term also refers to approaches aimed at minimising the use of pesticides (Coödinatiecommissie Onkruidonderzoek 1984), an alternative definition being a control system based upon the population of a harmful organism taking into account natural resistance factors and based upon a minimal use of techniques and products harmful to the environment.

The concept of integrated weed management is becoming more widely accepted and the approach is now being applied in irrigation and drainage management. This should include:

- careful irrigation water control to reduce drain discharge and thus facilitate control of weeds in drains
- minimising the movement and deposition of silt into and around the channels preventing the encouragement of excessive weed growth on accumulated sediment
- minimising the introduction of fertilisers and other nutrients into the water in the channels
- integrating harvesting of forage into the weed control programme

- preventing livestock from trampling down channel banks and hastening weed infestation.

As described at the outset of this chapter, it is unusual and unwise to rely on a single weed control method, e.g. only herbicides, or worse just one type of herbicide. A suite of methods is necessary typically combining manual, mechanical and environmental measures. The integration of such a range of techniques is important to ensure that they are effective and efficient.

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