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Aquatic and riparian plant management: controls for vegetation in watercourses

Technical guide

Project: SC120008/R2

Flood and Coastal Erosion Risk Management Research and Development Programme

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Miranda Kavanagh

Director of Evidence

Executive summary

This guidance provides watercourse managers in flood risk management operating authorities (both technical staff and field operatives) with a framework to help inform decisions on when and how to manage vegetation, taking into account the species present and the watercourse type. It updates previous aquatic and riparian vegetation management publications to take account of these changes.

This technical guide provides detailed information on the most important aquatic and riparian species in the UK. It describes the different types of watercourse and the range of management techniques (physical, chemical, biological, environmental and novel) available. Information is also given on the broad-scale impacts of aquatic and riparian plant management and the issues and factors to consider when planning any aquatic and riparian vegetation management operation.

It is designed to be read and used together with:

- Decision-making spreadsheet tool – a tool to help inform selection of the most appropriate technique(s) to manage a particular watercourse type, with a specific species problem

- Field guide – a concise guide to help collect the information needed to use the decision-making spreadsheet tool

The evidence on which this guidance is based is presented in an accompanying case study report and a literature review report.

Acknowledgements

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Additionally, we would like to thank all those who have provided information, case studies and photographs for inclusion in this guide.

Contents

1. Introduction

Watercourses are managed for many different reasons, sometimes with conflicting aims. The management of aquatic and riparian plants is essential to ensure the efficient functioning of many watercourses. It is important that management is cost effective, takes account of relevant legislation/restrictions and meets the objectives of the greatest number of watercourse users, while minimising any negative environmental impacts.

This guidance provides watercourse managers in flood risk management operating authorities (both technical staff and field operatives) with a framework to help inform decisions on when and how to manage vegetation, taking into account the species present and the watercourse type.

The way in which aquatic and riparian vegetation is managed has changed as a result of:

- legislative changes (see Appendix A - Legislative review)
- emerging novel techniques and technologies
- the evolution of best practice

This guidance updates previous aquatic and riparian vegetation management publications to take account of these changes.

The overall aim is to synthesise latest research to develop good practice guidance on the management of aquatic plants and vegetation both in and alongside watercourses. The guidance takes account of the range of management techniques available and different watercourse types.

1.1 Scope of the guidance

This guidance covers the management of aquatic and riparian vegetation, including algae, in England and Wales. It does not cover the management of vegetation in lakes or ponds, but it does include canals. Nor does it include the management of riparian trees and woody vegetation or vegetation within the wider floodplain.

For the purposes of this guidance, ‘riparian vegetation’ is defined as ‘the characteristic vegetation along watercourses that forms the link between the environments of water and land’ (Figure 1.1).

Riparian plant species discussed in this guidance include those typically found in marginal zones, providing a link between the environments of land and water and regularly inundated.

Although this guidance does not specifically cover terrestrial species, such as tall grasses or nettles, often found in bankside habitats, a number of the techniques discussed are applicable to these, particularly flail mowing (section 7.3.5) and grazing (section 7.6.1).

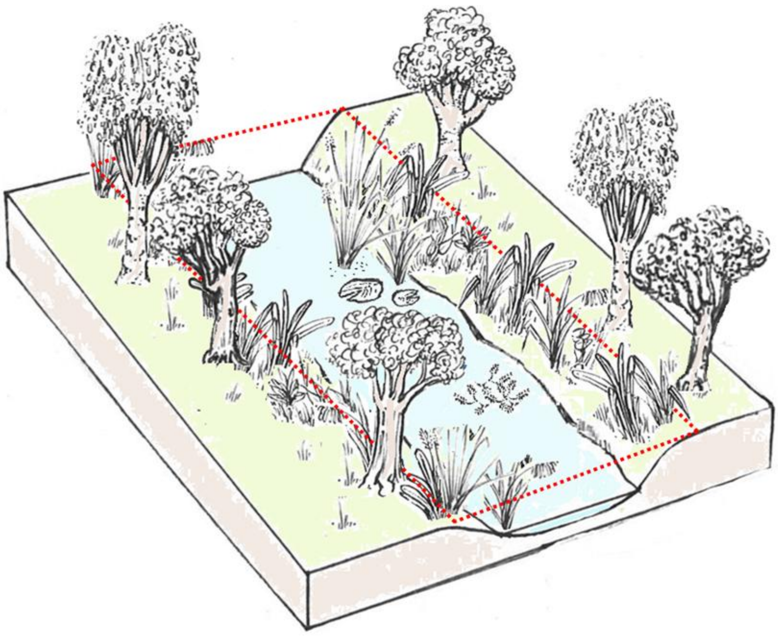


Figure 1.1 Riparian vegetation

Sources of further information

Management of riparian trees and woody vegetation:

- Environment Agency FCRM Asset Management Maintenance Standards
- *The Drainage Channel Biodiversity Manual* (Buisson et al. 2008)
- *Riparian Vegetation Management* (SEPA 2009)
- *The New Rivers & Wildlife Handbook* (Ward et al. 1994)

Management of terrestrial bankside species:

- Environment Agency FCRM Asset Management Maintenance Standards
- *The Drainage Channel Biodiversity Manual* (Buisson et al. 2008)

1.2 Target audience

The guidance is intended for use in catchments where aquatic and riparian plants need to be periodically controlled or removed. It is aimed at technical staff and field operatives in the operating authorities responsible for flood risk and water level management. For England and Wales these are:

- Environment Agency
- Natural Resources Wales
- Internal Drainage Boards (IDBs)
- Lead Local Flood Authorities (LLFAs) and local authorities
- Canal & River Trust

The information given in this guide will also be useful for other organisations that carry out aquatic and riparian vegetation management, such as:

- Natural England
- wildlife trusts
- rivers trusts
- angling trusts
- RSPB

The information in this guide can also be used by riparian landowners who want to manage aquatic and riparian vegetation within a watercourse on or adjacent to their property or land. It is recommended that landowners seek further advice from the Environment Agency, Natural Resources Wales or the relevant IDB or LLFA before managing aquatic and riparian vegetation in watercourses on or adjacent to their land.

1.3 Content of the guidance

The guidance consists of three interlinked items (Figure 1.2) designed to be read and used together:

- **Technical guide –** detailed information on planning, undertaking and monitoring aquatic and riparian vegetation management
- **Field guide** – a concise guide to help collect the information needed to use the decision-making spreadsheet tool
- **Decision-making spreadsheet tool –** a tool to help inform selection of the most appropriate technique(s) to manage a particular watercourse type, with a specific species problem

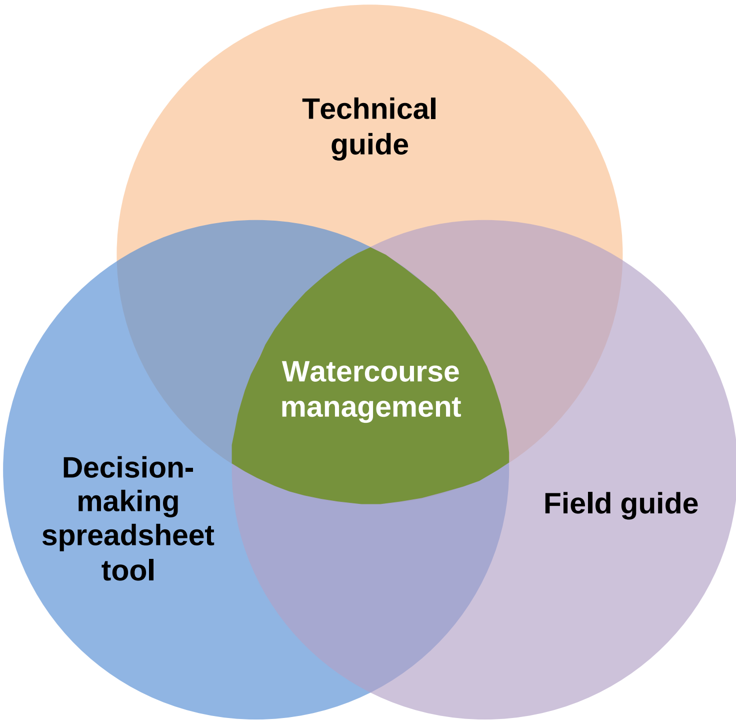


Figure 1.2 Interlinked guidance documents

All documents can be downloaded from the Environment Agency website.

1.4 Structure of this technical guide

This guide contains the following information:

- **Chapter 2** – background to the ecology and management of aquatic and riparian vegetation
- **Chapter 3** – broad-scale impacts of aquatic and riparian plant management
- **Chapter 4** – issues and factors to consider when planning any aquatic and riparian vegetation management operation
- **Chapter 5** – information on the key problematic aquatic and riparian species in the UK
- **Chapter 6** – watercourse types
- **Chapter 7** – aquatic and riparian vegetation management techniques
- **Chapter 8** – selecting a management technique using a decision-making spreadsheet tool
- **Chapter 9** – case studies
- **Chapter 10** – the role of monitoring

2. Ecology and management of aquatic and riparian vegetation

Vegetation is a natural and vitally important part of aquatic and riparian ecosystems. Excessive growth of aquatic and riparian vegetation can have adverse impacts on both the ecosystem itself and the human uses of the watercourse. This can result in the need for management.

2.1 Importance of aquatic and riparian vegetation

Aquatic and riparian plants are fundamental to the structure and function of many freshwater habitats. The benefits they bring include:

- aerating the water through photosynthesis
- providing shelter and refuge for riverine animals
- providing habitat and food for aquatic invertebrates, fish and a range of other species
- providing habitat connectivity and routes along which species can move and disperse
- improving water quality
- consolidating bed and bank substrates
- reducing the risk of bank erosion and scour
- mitigating the impacts of diffuse pollution by acting as a buffer
- reducing the risk of flooding through increased channel 'roughness' which slows flows passing downstream
- improving resilience against droughts by increasing the retention time of water
- providing amenity, aesthetic and recreational benefits

2.3 Types of aquatic and riparian plants

A number of species of aquatic and riparian plants can cause a range of problems, requiring different approaches to management. This guide splits the management of aquatic and riparian vegetation into a number of broad species groups, based on growth habit (Table 2.1).

Table 2.1 Types of aquatic and riparian plants

Group		Description	Example species
Submerged		These species have stems and leaves that grow beneath the surface of the water, although flowers may project above the water surface. Usually found in deeper water and rooted on the bottom, although a few species are free-floating within the water column.	Water-milfoils *Myriophyllum* spp. Parrot's-feather *Myriophyllum aquaticum* Submerged pondweeds *Potamogeton* spp. Water-crowfoots *Ranunculus* spp. Rigid hornwort *Ceratophyllum demersum* Mare's-tail *Hippuris vulgaris* Canadian waterweed *Elodea canadensis* Nuttall's waterweed *Elodea nuttallii* Curly water-thyme *Lagarosiphon major*
Floating-leaved	Free-floating	Species with some or all of the leaves floating on the water surface. Often found mixed in with emergent and submerged plants.	Duckweeds *Lemnaceae* Water fern *Azolla filiculoides*
	Floating-leaved rooted		Broad-leaved pondweed *Potamogeton natans* Water-lilies *Nuphar* spp. *and Nymphaea* spp. Fringed water-lily *Nymphoides peltata* Water-starworts *Callitriche* spp. Arrowhead *Sagittaria sagittifolia* Floating pennywort *Hydrocotyle ranunculoides* Water-primroses *Ludwigia* spp.
Emergent	Tall emergent	Plants whose stems and leaves are exposed above the normal water level. They have erect, aerial leaves and can grow both in water and temporarily drier conditions.	Common reed *Phragmites australis* Reedmaces *Typha* spp. Reed sweet-grass *Glyceria maxima* Reed canary-grass *Phalaris arundinacea* Common club-rush *Schoenoplectus lacustris* Branched bur-reed *Sparganium erectum* Tall sedges *Carex* spp.
	Broad-leaved		Fool's water-cress *Apium nodiflorum* Lesser water-parsnip *Berula erecta* Water-cress *Rorippa nasturtium-aquaticum* Water-soldier *Stratiotes aoides* Australian swamp stonecrop *Crassula helmsii*
Algae		Plants classified botanically according to the colour of pigment they contain. Usually quite simple in structure.	Filamentous green algae Unicellular green algae Cyanobacteria Stoneworts (charophytes)

These groups are important because management options usually relate to the growth form of the plant rather than its taxonomy. To select the most effective management technique it is recommended that the plant is identified to species level.

Some species can exhibit different growth habits and could fall into a number of categories. For example, arrowhead *Sagittaria sagittifolia* can have submerged linear leaves alongside floating and emergent arrow-shaped leaves. Also, common club-rush *Schoenoplectus lacustris* can have both tall emergent stems and submerged floating leaves. In such cases this guide discusses these species in the growth habit group within which they tend to be most problematic. For example, stands of tall emergent common club-rush *Schoenoplectus lacustris* cause more problems than its submerged linear leaves; this species is therefore included within the tall emergent group.

Table 2.1 lists the key aquatic and riparian plants which cause the most issues in watercourses, including non-native invasive species. The guide also covers the non-native invasive bank species, Japanese knotweed *Fallopia japonica*, giant hogweed *Heracleum mantegazzianum* and Himalayan balsam *Impatiens glandulifera.* These species are included because the management of other aquatic and riparian plant species can often be impacted upon/ restricted by their presence.

Further details on each problematic species from Table 2.1 are provided in Chapter 5.

2.4 Reasons for aquatic and riparian plant management

UK watercourses perform many different roles (Figure 2.1), sometimes with conflicting management objectives. Aquatic and riparian plants can cause problems when the rate of vegetation growth adversely affects biodiversity or human uses of the watercourse.

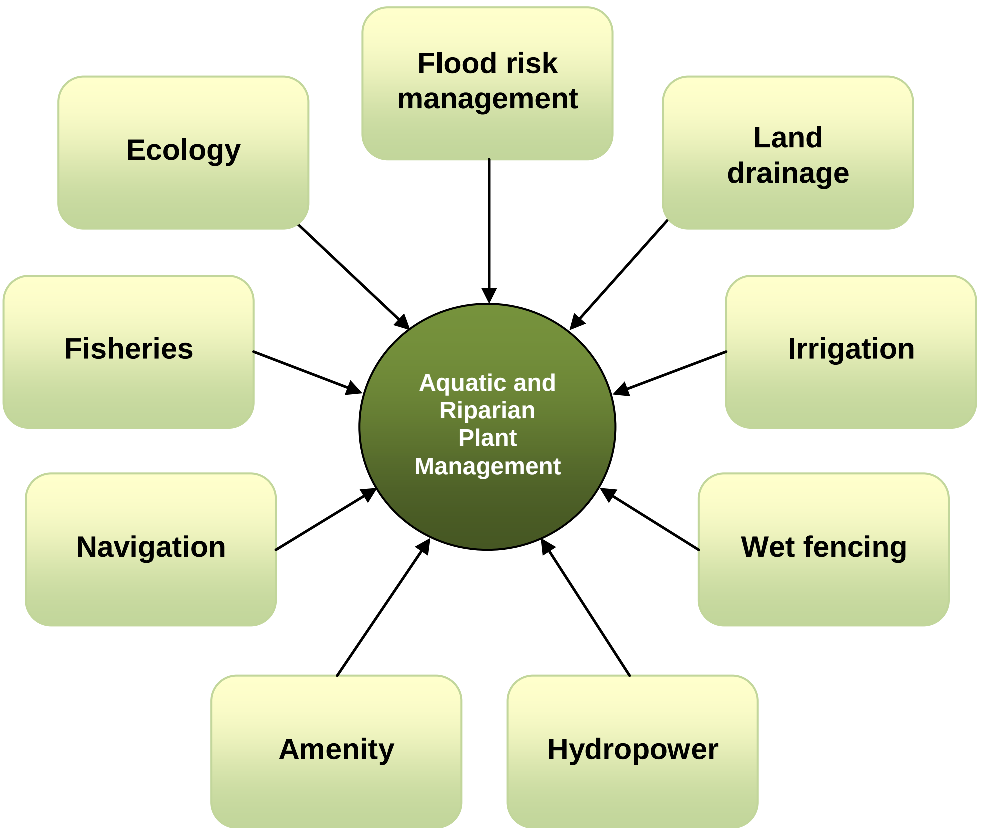


Figure 2.1 Drivers of aquatic and riparian plant management

Aquatic and riparian plants need to be managed because they can:

- reduce channel capacity, raise water levels and impede flow resulting in waterlogging or flooding
- cause erosion and siltation
- block pumps, sluices, weirs and filters
- impede navigation
- prevent fishing and damage of fish spawning habitats
- reduce amenity value, causing aesthetic and economic impacts
- destroy wildlife habitats and lead to the domination of a single, often non-native invasive species
- deoxygenate water
- reduce water quality (unicellular green algae and cyanobacteria can release toxins into the water)
- cause public health issues (water-borne pests and diseases)
- create bad odours and taint
- create a safety hazard, to both humans and livestock

Figure 2.2 shows some examples of problematic aquatic and riparian vegetation.

Figure 2.2 Examples of problematic aquatic and riparian vegetation

2.4.1 Reducing flood risk

Aquatic and riparian plants are often managed to reduce flood risk. Vegetation can increase flood risk by obstructing the flow of water, reducing channel capacity, obstructing in-channel structures and encouraging silt accumulation. These problems typically arise in summer when plant growth is at its maximum. The dead stems and leaves of many species, particularly emergent ones, can persist into autumn and winter causing additional problems.

Detached plant material, floating species and algae can also cause problems by floating downstream, blocking pumps, sluices, weirs and filters. They can also block the intakes of hydroelectric turbines, drinking water and irrigation systems.

Example: Brompton Beck, North Yorkshire

Brompton Beck frequently floods some of the houses in the village of Brompton near Northallerton. Lesser water-parsnip *Berula erecta* is the key problem species here as it can cover the whole channel width, reducing flow conveyance.

During high flows this relatively fragile species also dislodges, breaks up and flows downstream where it blocks the bridge at the downstream end of the village green, contributing to local flooding issues. To reduce this risk, in 2010 the beck was de-weeded using an excavator fitted with a solid bucket. Vegetation has regrown within a few years meaning repeat or alternative management is required.

2.4.2 Agricultural purposes

Aquatic and riparian plants also need to be managed for agricultural purposes. When vegetation chokes watercourses adjacent to farmland it can cause water levels to rise, resulting in land becoming waterlogged and under-drainage systems becoming ineffective; this affects farming operations.

On agricultural land it is also necessary to ensure:

- summer flows are sufficient to allow irrigation systems to work effectively
- water tables are high enough to encourage crop development
- wet fences are maintained to manage livestock safety and movements

2.4.3 Recreation and commercial uses

Excessive plant growth can impede fishing, boating and commercial navigation.

Management may also be needed to facilitate recreation, access and for aesthetic reasons.

Dense vegetation growth can not only impair the activities of anglers, but it can also reduce spawning and fish productivity.

These problems tend to arise in the summer and autumn when the majority of boat traffic and recreation activities take place.

2.4.4 Ecological reasons

Aquatic and riparian plant management may be conducted for ecological reasons to benefit the habitats and species within the watercourse. This may involve controlling non-native invasive species, or when a single species or group of species becomes so dominant that it limits the growth of other plants.

Management of non-native invasive species can also help to deliver objectives of the Water Framework Directive (WFD) by allowing native species to thrive without competition. This can also enhance conditions for fish, invertebrates, phytoplankton and phytobenthos, and can help to reduce bank erosion.

Management may also be conducted to encourage a particular target species, for example within a Site of Special Scientific Interest (SSSI) or other designated site, or to control natural succession to scrub and woodland in the riparian zone.

Example: Skinner's Reen and Chapel Reen, Gwent Levels

The Gwent Levels are ecologically important with the network of drainage ditches providing ideal habitats for a range of rare and notable plant species including rootless duckweed *Wolffia arrhiza*, corky-fruited water-dropwort *Oenanthe pimpinelloides* and hairlike pondweed *Potamogeton trichoides*.

Skinner's Reen and Chapel Reen, within the Nash and Goldcliff SSSI part of the Gwent Levels, are of particular importance for hairlike pondweed *P. trichoides*. The management of these watercourses has been tailored by the Caldicot and Wentlooge Levels IDB to conserve and enhance this species. Management involves keeping channels open to reduce competition from hardier, more dominant pondweeds, allowing the populations of hairlike pondweed to thrive. These short rotation de-weeding operations allow the populations to be maintained within these watercourses.

2.4.5 Deoxygenation

Deoxygenation of water is a potential problem linked to aquatic plants. This is particularly relevant to algae during hot weather conditions as they can absorb large quantities of oxygen at night, resulting in very low oxygen levels around dawn. This can result in the death of fish and invertebrates.

Deoxygenation may also occur when floating plants cover the water surface and prevent light from reaching submerged species below, causing them to die back. Deoxygenation not only impacts on biodiversity, but can also cause odour issues.

2.5 Watercourse management

Vegetation within watercourses has been managed to meet human needs for centuries, with operations becoming increasingly mechanised over recent decades. During the post-war era as agriculture intensified, the need for increased watercourse management for land drainage developed, and this continued throughout the 1960s and 1970s. Increased population size and development in floodplains further increased the need for watercourses to be managed for flood risk management purposes.

Over recent years, restricted budgets and increased environmental concerns have reduced the frequency and intensity with which operating authorities undertake vegetation management. There is now a need to ensure:

- any vegetation management is carefully planned and prioritised
- it is conducted in a cost-effective and environmentally sustainable manner

Aquatic and riparian plant management techniques fall under four main categories:

- **Physical** – the active removal of plant material from a watercourse
- **Chemical** – the application of herbicides and other substances to manage growth of plants
- **Environmental** – the alteration of conditions within or surrounding the watercourse to reduce or prevent plant growth
- **Biological** – the use of biological control agents to control unwanted species or excessive plant growth

A number of emerging **novel** techniques for vegetation management are also becoming available.

Table 2.2 lists all the techniques available in the UK at the time of writing. Further details on each of these techniques are provided in Chapter 7.

Table 2.2 Possible techniques for vegetation management

Category	Technique
Physical	Hand pulling
	Hand cutting
	Hand raking
	Mechanical harvesters
	Weed boats
	Amphibious vehicles
	De-weeding with a weed bucket
	De-weeding with a solid bucket
	Excavator and tractor mounted cutter/ flail
Chemical	Glyphosate-based herbicide
	Glyphosate-based herbicide with adjuvant
	Barley straw
	Barley straw extract
Environmental	Shading through tree/ hedgerow/ bankside planting
	Fencing to allow bankside vegetation growth for shading
	Shading with native, broad-leaved floating species
	Shading with opaque materials suspended over water
	Shading with benthic barriers
	Dyes
	Water level manipulation
	Manipulation of flow characteristics
	Channel narrowing to increase velocity (two-stage channel)
	Buffer strips
	Diffuse and point source pollution management
	Nutrient-binding chemicals
	Disturbance by boat traffic
Biological	Grazing of banks by cattle, sheep and horses
	Waterfowl
	Native fish species
	Invertebrates (for example, *Daphnia* spp., weevils)
Novel techniques	Hot foam
	Ultrasound
	Electromagnetic water treatment
	Suction harvesting
	Diver-operated suction harvesting
	Hydro Venturi
	Infrared

2.6 Factors contributing to aquatic and riparian plant problems

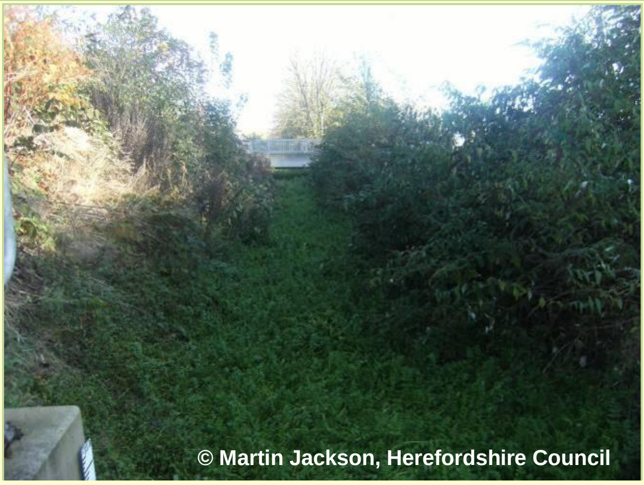
It is the excessive growth of aquatic and riparian vegetation that adversely affects the biodiversity or human function of a watercourse, which in turn drives the need for management. Excessive growth can be caused by disturbance, nutrient enrichment and poor water quality.

When watercourses and their riparian zones become disturbed, the natural balance among plant species and geomorphological conditions can be disrupted and this may lead to excessive plant growth. Artificial and heavily modified watercourses create in-channel conditions that are ideal for excessive plant growth. Many watercourses in the UK are also affected by human activities, which often create disturbed conditions, such as river engineering works, land drainage, species introductions, boat traffic and erosion. Where habitats are suitable, disturbed conditions can be exploited by aquatic plants which then require management as they come to dominate the environment. The management undertaken may itself, in some circumstances, create continued disruption to the environment which perpetuates the need for further management.

Example: Chatterley Brook, Ross-on-Wye, Herefordshire

Chatterley Brook is a tributary of the River Wye that flows through Ross-on-Wye. A section of this watercourse was subject to flood risk management works which resulted in the removal of some tree cover and earthworks which created bare, exposed banks.

Soon after the works, fool's water-cress *Apium nodiflorum* colonised the watercourse and developed into a single-species stand, becoming very dense, reducing channel capacity and impeding flows. It was initially thought that species diversity would increase as the watercourse recovered from the works, but this has not been the case and fool's water-cress remains dominant.



In these disturbed and heavily modified situations, where aquatic and riparian vegetation is problematic, reinstating natural fluvial geomorphological process may help to reduce the problems caused.

Artificially elevated nutrient levels in watercourses, particularly phosphate, can cause excessive vegetation growth. Nutrients in watercourses mainly arise from diffuse pollution from land (especially agricultural land) and urban run-off, plus point sources from wastewater treatment, industrial and domestic inputs. Deposition of ammonia, nitrate and other forms of nitrogen from the atmosphere can also be an important source of nitrogen in some upland catchments where intensive agricultural activity is limited. Increased eutrophication over recent decades has been reported as increasing the problems created by excessive plant growth in watercourses in the UK.

Excessively polluted waters, whether affected by organic, pesticide, herbicide or inorganic contaminants (for example, heavy metals), may cease to be suitable for aquatic plant growth. A lack of these plants in lowland reaches of rivers is often an indicator of poor water quality, but can also be a result of other factors (for example, depth, flow, navigation and turbidity).

Further information on river restoration and channel re-naturalisation

- River Restoration Centre website (www.therrc.co.uk)
- Healthy Catchments website (www.restorerivers.eu/RiverRestoration/Floodriskmanagement/HealthyCatchmentsmanagingforfloodriskWFD/tabid/3098/Default.aspx)

2.7 Future changes to aquatic and riparian plant problems

Climate warming may lead to the need for more frequent and intensive management as a result of longer growing seasons, more vigorous plant growth, higher rainfall and increased flood risk. Warmer water, more nutrients and slower flows may have adverse effects on a number of species, including a potential reduction in the growth of submerged species, but an increase in the growth of floating plants, non-native invasive species and also epiphytic algae. Watercourse management requirements may therefore need to be adapted.

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Water hyacinth *Eichhornia crassipes*

New non-native invasive species may also become a problem. For example, species such as water hyacinth *Eichhornia crassipes* and water lettuce *Pistia stratiotes*, which are currently a problem in southern Europe, may move northwards and become increasingly problematic as a result of climate change. Non-native species which are currently non-invasive may also start to become more problematic if barriers to their growth, such as temperature, are removed.

Table 2.3 summarises the non-native invasive aquatic species identified as of concern in the UK. It sets out their status in terms of listing in Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) (WCA), their ranking according to Plantlife's horizon scanning for invasive, non-native plants (Thomas 2010, pp. 12-18) and the current WFD classification of aquatic alien species (UKTAG 2013a).

Table 2.3 Non-native invasive aquatic plant species in the UK

Scientific name	Common name	Listed on WCA Schedule 9	Plantlife risk assessment	UKTAG (2013) classification
Acorus calamus	Sweetflag	No	Urgent	Low impact
Aponogeton distachyos	Cape pondweed	No	Moderate	Low impact
Azolla filiculoides	Water fern	Yes	Critical	High impact
Cabomba caroliniana	Fanwort	Yes	Critical	Not listed
Crassula helmsii	Australian swamp stonecrop	Yes	Critical	High impact
Eichornia crassipes	Water hyacinth	Yes	Moderate	Low impact
Egeria densa	Large-flowered water-thyme	No	Moderate	Unknown
Elodea (all species)	Waterweeds	Yes	Critical (*E. callitrichoides, E. canadensis, E. nuttallii*)	High impact (*E. canadensis, E. nuttallii*)
Fallopia japonica	Japanese knotweed	Yes	Not listed	High impact
Fallopia sachaliensis	Giant knotweed	Yes	Not listed	High impact
Fallopia sachaliensis x Fallopia japonica	Hybrid knotweed	Yes	Critical	High impact
Gunnera tinctoria	Giant rhubarb	Yes	Urgent	Not listed
Heracleum mantegazzianum	Giant hogweed	Yes	Not listed	High impact
Hydrocotyle ranunculoides	Floating pennywort	Yes	Critical	Not listed
Impatiens glandulifera	Himalayan balsam	Yes	Not listed	High impact
Lagarosiphon major	Curly water-thyme	Yes	Critical	High impact
Lemna minuta	Least duckweed	No	Moderate	Unknown
Ludwigia grandiflora	Water-primrose	Yes	Critical	High impact
Ludwigia peploides	Floating water-primrose	Yes	Critical	Not listed
Myriophyllum aquaticum	Parrot's-feather	Yes	Critical	High impact
Petasites japonicus	Giant butterbur	No	Critical	Low impact
Pistia stratiotes	Water lettuce	Yes	Moderate risk	Not listed
Sagittaria latifolia	Duck-potato	Yes	Critical	Not listed
Vallisneria spiralis	Tapegrass	No	Urgent	Low impact

The following species are now banned from sale in the UK:

- floating pennywort *Hydrocotyle ranunculoides*

- Australian swamp stonecrop *Crassula helmsii* (also known as New Zealand pigmyweed)
- parrot’s-feather *Myriophyllum aquaticum*
- water fern *Azolla filiculoides*
- water-primrose *Ludwigia grandiflora*

Example: Be Plant Wise Campaign

The Be Plant Wise campaign, launched by Defra and the Scottish Government, is designed to raise awareness among gardeners, pond owners and retailers of the damage caused by non-native invasive aquatic plants in the wild. The campaign encourages the public to dispose of plants correctly and works with the horticultural trade and retailers in promoting best practice. Campaigns such as this should hopefully reduce the incidence of non-native invasive species occurring in aquatic and riparian environments.

Further information can be found at on the Non-native Species Secretariat (NNSS) website (www.nonnativespecies.org/beplantwise/)

Not all of the species listed in Table 2.3 are yet problematic in the aquatic and riparian environment in the UK. Specific details and discussion of the most effective management techniques for those not yet considered problematic are not given in this guide.

Water hyacinth *Eichhornia crassipes*
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3. Impacts of vegetation management

It is essential to understand any potential impacts of aquatic and riparian vegetation management techniques. This chapter examines potential broad-scale impacts. Specific impacts relating to particular techniques are discussed in Chapter 7.

While some changes and impacts can be anticipated, others may not, leading to unexpected results. This highlights the importance of monitoring and adaptive management, both discussed in Chapter 10.

3.1 Environmental impacts

All management operations conducted within a watercourse will have an environmental impact, which will vary in nature and magnitude.

Environmental impacts can either be direct or indirect. During any management operation direct impacts may arise on non-target species. For example, many physical techniques not only actively remove the target plant species from the watercourse, but also the non-target species growing or living amongst them. This can remove habitats of certain species and in some cases result in injury or death. Where protected species are present, such as water vole *Arvicola amphibius* or floating water-plantain *Luronium natans* this could have a significant impact on their populations. Similarly, management using herbicides can directly impact on non-target species because it can be very difficult to treat the target species only. Techniques such as grazing or shading also impact on the wider environment, not just the target species. The wider direct impacts of management need to be considered before carrying out any operation, particularly where rare and/ or notable species are present.

Indirect impacts can also arise as a result of aquatic and riparian plant management.

For example, physical techniques can result in significant quantities of vegetative material being released into the watercourse, which subsequently dies and decomposes causing deoxygenation and potentially killing fish and other organisms.

Chemical techniques can also have a similar impact where significant quantities of plant material decompose within the channel.

Shading techniques that cause die-back of submerged vegetation can also cause deoxygenation.

3.2 Impacts on vegetation communities

The longer-term impacts of management operations on vegetation communities also need to be taken into account when planning and carrying out management programmes.

Regular watercourse management will change the characteristics of the vegetation community, which could then have impacts on aquatic macroinvertebrate populations and other fauna. Regular management activities, such as cutting, has also been shown to reduce the diversity of aquatic plants in some circumstances (Baattrup-Pedersen et al*.* 2003), which could impact on the ecological status of a watercourse.

When one type of aquatic plant is removed it is often replaced by another group. For example, when emergent species are removed by management operations, they are frequently replaced by submerged species. When submerged species are removed they are often then replaced by algae. Following the majority of management operations, algae are often the first species to re-establish.

In response to management, the species composition within a watercourse can gradually change as species susceptible to a particular form of management are replaced by more tolerant species. Possible changes in vegetation communities within a watercourse must be recognised as a potential consequence of management operations, with the aim being to retain some areas of vegetation unmanaged so that recolonisation can occur and species are not lost.

3.3 Geomorphological impacts

Inappropriate management techniques can lead to both short- and long-term hydromorphic damage to watercourses. For example, grazing too close the channel edge can, on some watercourse types, lead to considerable increases in fine sediment supply to the channel. This can have a direct impact on in-channel habitats such as smothering fish spawning gravels.

Different vegetation management techniques are likely to have varying impacts on watercourses depending on their type. Some watercourse types are more sensitive than others to change or intervention. Developing an understanding of the functional geomorphic watercourse type will help to:

- select appropriate vegetation management techniques
- understand how a particular watercourse type may respond to that technique

Selecting suitable techniques for a particular watercourse type will also help to ensure that their effect is not detrimental to the watercourse and its WFD status. Watercourses with altered geomorphology, for example over-deepened or over-widened channels, are often those which have the most severe problems with aquatic and riparian vegetation. While continued vegetation management is likely to be required to maintain channel capacity, it should be done sensitively to minimise the geomorphological and ecological impact (see Chapter 7).

4. Planning aquatic and riparian plant management

Aquatic and riparian plant management is often an essential part of watercourse maintenance. If it is well planned and executed correctly, it can be cost-effective and environmentally beneficial. If poorly executed, it can be expensive, environmentally damaging and of limited benefit.

The purpose of this guide is to help watercourse managers select the most appropriate technique(s) to manage aquatic and riparian vegetation in a specific type of watercourse. This chapter outlines the process through which aquatic and riparian management operations should be planned.

4.1 Planning management

For it to be effective and beneficial, aquatic and riparian vegetation management needs to be planned carefully (Figure 4.1). The checklist given in Table 4.1 will aid watercourse managers planning aquatic and riparian plant management. It includes the main considerations to be taken into account and identifies the actions required before management is carried out (as described in section 4.4). This list is not exhaustive and other actions may be required beforehand. These should be determined on a site-by-site basis.

Table 4.1 Planning checklist

Consideration	Action required
Is the watercourse designated or does it flow into, through or out of a designated nature conservation site?	If **YES** – contact Natural England or Natural Resources Wales as appropriate. Consent may be required.
Is the watercourse located adjacent to a scheduled monument?	If **YES** – contact English Heritage or Cadw as appropriate. Consent may be required.
Does the watercourse support protected species?	If **YES** – implement appropriate mitigation measures and working practices when conducting management. Consider modifying management, including its timing, to avoid adverse impacts. If adverse impacts cannot be avoided, contact Natural England or Natural Resources Wales for further advice and to obtain a licence if required.
Does the watercourse support notable and/ or rare species?	If **YES** – ensure appropriate working practices when undertaking management. Consider modifying management to avoid adverse impacts. Contact Natural England or Natural Resources Wales for further advice if required.
Are spawning fish present?	If **YES** – ensure appropriate working practices when carrying out management. If possible, time works to avoid spawning season. Contact the Environment Agency for further advice if required.
Do the proposed management	If **YES** – assess the ecological and

Consideration	Action required
works require a WFD Compliance Assessment?	hydromorphological impacts of the proposed management works. Consult the Environment Agency/ IDB/ LLFA for further advice.
Do the proposed management works fall under the Environmental Impact Assessment Regulations?	If **YES** – assess the environmental impacts of the proposed management works and determine whether an Environmental Statement is required. Advertise and consult on the outcome of the assessment.
Have all health and safety implications been identified?	Ensure that: • all necessary risk assessments are made • safe systems of work are in place • operatives are properly trained, instructed and provided with appropriate personal protective equipment (PPE)
Has biosecurity been considered?	Assess the level of risk posed by the management works and put in place appropriate biosecurity measures.
Will the proposed management works create waste which requires disposal?	If **YES** – register waste exemptions or apply for permits where necessary. If waste has to be removed from site, ensure it is taken by a licensed waste carrier to a suitably authorised landfill site.
Do the proposed management works require flood defence/ land drainage consent?	If **YES** – apply to the appropriate authority for consent. Holding preliminary discussions with the appropriate authority before submitting any application is advised.
Do the proposed management works require the use of herbicide in or near water?	If **YES** – apply to the Environment Agency/ Natural Resources Wales for agreement. Further guidance on the use of herbicides in or near water is provided in section 7.4.1.
Has the possibility of partnership working been explored?	Identify and consult with any other interested parties and consider setting up a partnership/ working group to carry out the planned management.
Has management been considered in the context of the wider catchment?	Ensure upstream and downstream watercourse function(s) and management requirements are identified and integrated within a catchment-scale approach.

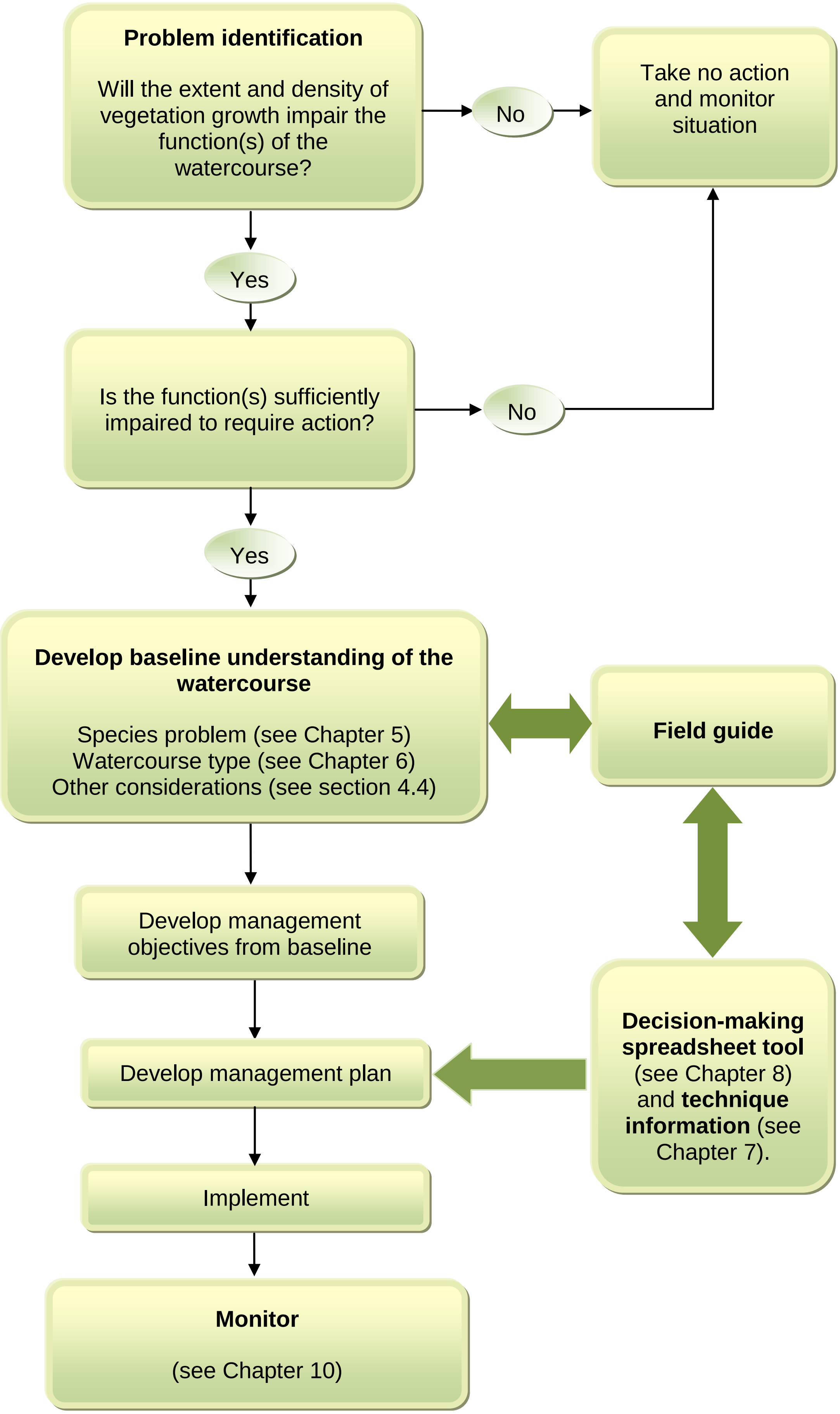


Figure 4.1 Planning management of aquatic and riparian vegetation

4.2 Problem identification

The first stage of planning is to identify if there is a problem and then determine if management is needed.

To identify the problem it is necessary to understand the function(s) of the watercourse. For example, if the watercourse performs a flood risk management function is vegetation growth increasing flood risk?

The first step is to determine whether the extent and density of vegetation growth sufficiently impairs the watercourse function(s) for action to be taken. In some cases the function(s) of the watercourse may only be partially impaired and a decision could be taken to 'take no action'.

Determining whether watercourse function(s) will be impaired enough to require management should be assessed on a site-specific basis using professional judgement.

4.3 Develop baseline understanding

To help make the assessment as to whether the watercourse function is impaired enough to require management, it is important to have a baseline understanding of the watercourse including:

- watercourse function(s)
- problematic species and where they occur (see Chapter 5)
- watercourse type (see Chapter 6) and its physical characteristics
- other considerations at the site (see section 4.4)

4.4 Management considerations

Where management is needed, a number of considerations need to be taken into account. These are summarised in Figure 4.2.

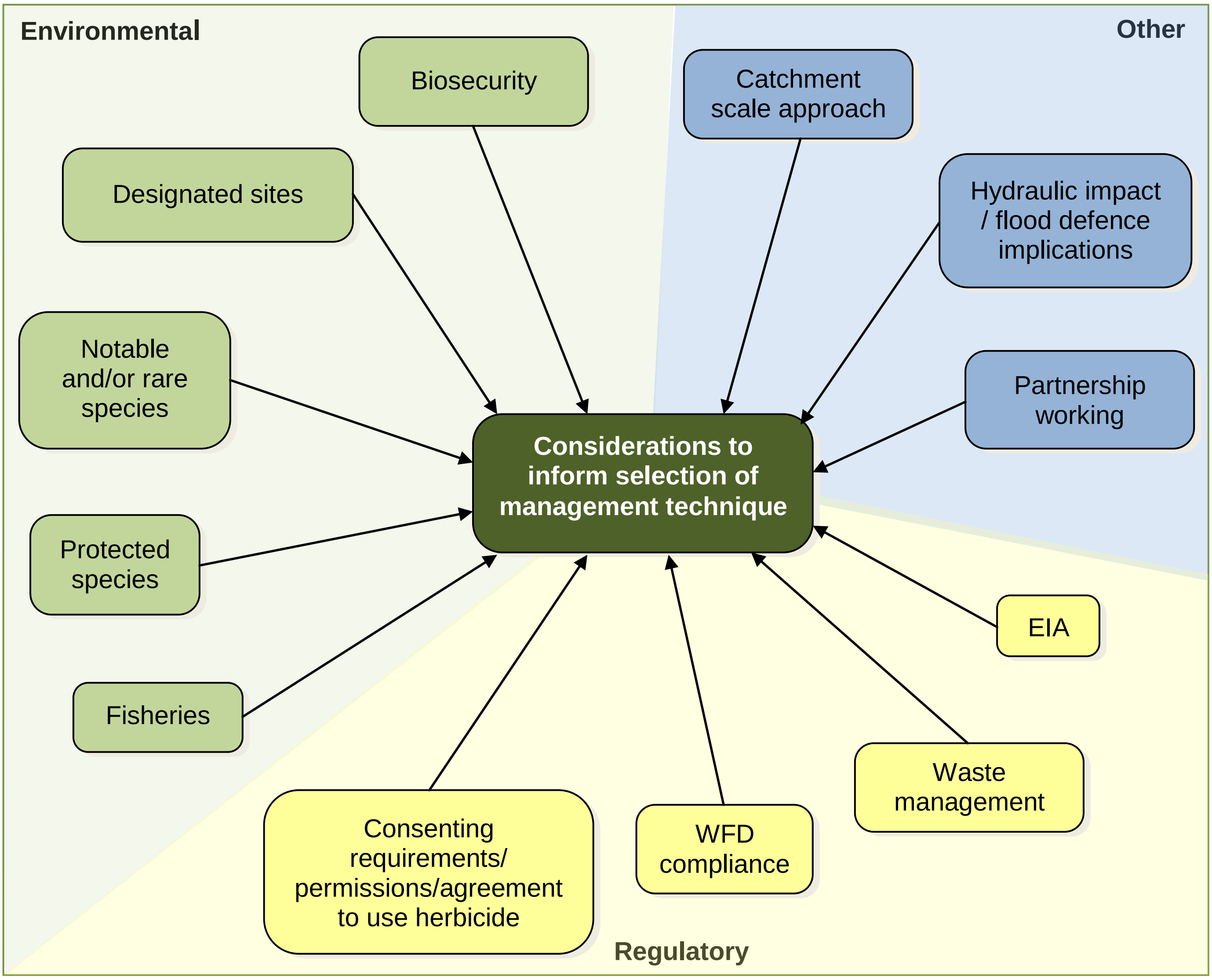


Figure 4.2 Considerations to inform selection of management technique

4.4.1 Designated sites

A number of rivers and other watercourses are protected by statutory designation, for example, Special Area of Conservation (SAC), Special Protection Area (SPA), Ramsar sites and/ or SSSI. These sites are designated as they contain habitat types and species of nature conservation value described as special interest features. All designated sites have conservation objectives which define the desired state for each of these features. When these features are being managed in a way which maintains their nature conservation value then they are said to be in favourable condition.

The management of aquatic and riparian plants may therefore be required to maintain or restore the condition of designated sites. This may include sites where:

- water levels and flow are critical to the site's condition
- non-native invasive species are having an adverse impact on the interest features of the site
- the interest features include certain aquatic and riparian plants that require management to maintain or enhance their populations

Example: Watercourses designated for their aquatic plant communities

A number of watercourses are designated because they contain an abundance of water-crowfoots *Ranunculus* species (*R. fluitans*, *R. penicillatus* ssp. *penicillatus*, *R. penicillatus* ssp. *pseudofluitans*, and *R. peltatus* and its hybrids) which form a priority habitat of international importance, listed in Annex I of the Habitats Directive. This habitat provides cover and food for a range of species, particularly invertebrates and fish, and may also influence and modify flow, nutrient and sediment dynamics.

There are several variants of this habitat in the UK, depending on geology and river type. In each, water-crowfoot *Ranunculus* species are associated with a different assemblage of aquatic plants, such as water-cress *Rorippa nasturtium-aquaticum*, water-starworts *Callitriche* spp., water-parsnips *Sium latifolium* and *Berula erecta*, water-milfoils *Myriophyllum* spp. and water forget-me-not *Myosotis scorpioides*. In some rivers, the cover of these may exceed that of water-crowfoot *Ranunculus* spp.

Chalk rivers and streams, for example, the River Itchen in Hampshire, are probably the most extensively managed watercourse type containing this habitat, with a long established history of in-stream vegetation management to maintain habitat diversity and also to reduce flood risk and enable fishing. The frequency, extent and timing of management are crucial to ensure the nature conservation value of the habitat is maintained.

Any aquatic and riparian plant management proposed within designated watercourses must be consistent with the conservation objectives defined by Natural England or Natural Resources Wales, and must receive formal consent before work begins.

The presence of SSSIs can also constrain the management of aquatic and riparian vegetation, potentially compromising the requirements of other watercourse functions (for example, flood risk management). For example, the management of a designated watercourse, which is usually agreed in writing with Natural England or Natural Resources Wales, may require incorporation of practices or timing restrictions that would not apply in non-designated watercourses. Watercourses may also flow into, through or out of designated sites and therefore their management could impact on the special interest features for which they are designated.

It is essential to consult Natural England or Natural Resources Wales before introducing or altering plant management techniques within designated watercourses and/ or those flowing into, through or out of designated sites as these could impact on the special interest features for which they are designated. This will ensure:

- the management proposed conserves and enhances the features of interest
- all necessary prior consents are obtained

Written consent from Natural England or Natural Resources Wales is needed before carrying out any management operation that could damage the special interest of a designated site. Natural England or Natural Resources Wales may specify any management activities deemed necessary to conserve and enhance the features of interest.

The presence of designated heritage sites, for example, scheduled monuments, immediately adjacent to a watercourse, could also constrain aquatic and riparian plant management activities. Consent may be required from English Heritage (in England) or Cadw (in Wales) for the depositing of any plant material removed from a watercourse on land in, on or under which there is such a monument.

Sources of further information

Designated nature conservation sites:

- Multi Agency Geographic Information for the Countryside (MAGIC) (www.magic.gov.uk)
- Natural England (www.naturalengland.org.uk/ourwork/conservation/designations/sssi/default.aspx)
- Natural Resources Wales (http://naturalresourceswales.gov.uk/our-work/policy-advice-guidance/designated-sites/?lang=en)

Scheduled monuments:

- English Heritage (www.english-heritage.org.uk/professional/advice/our-planning-role/consent/smc/)
- Cadw (http://cadw.wales.gov.uk/historicenvironment/help-advice-and-grants/makingchanges/schedmonconsent/?lang=en)

4.4.2 Protected species

A number of species associated with watercourses receive special protection under various European and UK laws. These include:

- water vole *Arvicola amphibius*
- otter *Lutra lutra*
- Desmoulin's whorl snail *Vertigo moulinsiana*
- white-clawed crayfish *Austropotomobius pallipes*
- Atlantic Salmon *Salmo salar*
- bullhead *Cottus gobio*

Certain species of plant are also protected such as floating water-plantain *Luronium natans*.

A number of watercourses are designated due to the presence of protected species. For some of these sites the management of aquatic and riparian plants is required to maintain their nature conservation interest.

Example: Lesser whirlpool ramshorn snail *Anisus vorticulus*

The lesser whirlpool ramshorn Snail *Anisus vorticulus* is a rare snail that occurs in ditches parts of the Norfolk Broads, the Arun Valley and an area centred on the Pevensey Levels. Ditches that are either completely cleared of vegetation or are choked with weed are unsuitable for this species, and therefore partial and carefully planned vegetation management is required to maintain viable populations. Natural England has devised a protocol for the management of watercourses inhabited by the lesser whirlpool ramshorn snail (Natural England 2014). This has to be conducted under licence to ensure activities are lawful and to provide the best conditions to prevent the snails from becoming extinct.

Example: Floating water-plantain *Luronium natans* in the Wyrley & Essington Canal and the Cannock Extension Canal SAC

In 2010, the Canal & River Trust began a project to manage the Wyrley & Essington Canal and the Cannock Extension Canal SAC for the benefit of floating water-plantain *Luronium natans*. The aims of the project were to increase populations of floating water-plantain and to extend the amount of suitable habitat for this rare species through appropriate management techniques while taking into account navigation needs*.* At this site, floating pennywort *Hydrocotyle ranunculoides* and Australian swamp stonecrop *Crassula helmsii* were identified as a particular issue, adversely impacting upon the canal habitat.

The ultimate goal of the project was to bring the Cannock Extension Canal SAC into favourable condition, with the proposed vegetation management including:

- management of non-native invasive species through monitoring and removal on-sight and mechanical removal of larger infestations combined with herbicide treatment
- tree and scrub management to reduce shade and leaf litter and open up new areas of suitable habitat for floating water-plantain *Luronium natans*
- management of yellow water-lily *Nuphar lutea* where this is reducing the amount of suitable habitat available for floating water-plantain *Luronium natans*

This vegetation management was combined with other measure to manage bankside habitats and silt within the canal. All works were carried out in agreement with Natural England.

The management of aquatic and riparian vegetation has the potential to adversely impact on protected species found within the watercourse and also those that may be located on the banks or within adjacent habitats, for example, nesting birds, water vole *Arvicola amphibius*, otter *Lutra lutra*, white-clawed crayfish *Austropotamobius pallipes*, badger *Meles meles* and great crested newt *Triturus cristatus*.

When planning the management of aquatic and riparian plants within watercourses, it is important to know if protected species are present. Operating authorities that conduct management on a regular basis are likely to have a database of protected species records. Where no records exist, information may be available from desk-based sources such as the National Biodiversity Network (NBN) Gateway (https://data.nbn.org.uk), local wildlife groups and/ or Local Environmental Records Centres (www.alerc.org.uk).

Surveys for protected species may be required.

If it is thought that proposed management techniques are likely to result in an offence being committed in relation to protected species, the following steps should be taken.

- Modify the proposed management technique to avoid impacts and hence an offence being committed.
- Train staff and/ or contractors carrying out the management.
- Implement appropriate mitigation measures and working practices when undertaking management.

The examples below illustrate how the presence of frequently encountered protected species may affect the management of watercourses.

Example: Vegetation management and nesting birds

Under Section 1 of the Wildlife and Countryside Act 1981 (as amended) it is an offence (with the exception of species listed in Schedule 2) to intentionally:

- kill, injure or take any wild bird
- take, damage or destroy the nest of any wild bird while that nest is in use or being built
- take or destroy an egg of any wild bird

This constrains aquatic and riparian vegetation management, as in many locations this vegetation provides habitat for nesting waterfowl (for example, moorhen and mallard) and a number of wetland passerines (for example, reed bunting and sedge warbler). Management by physical means, such as flail mowing and de-weeding, could damage and/ or destroy nests, which would be an offence. It is important that vegetation management is carried out outside the bird breeding season (March to September) or preceded by a survey for nests.

More easily disturbed and rarer species (for example, kingfisher) are additionally listed on Schedule 1 of the Act, receiving further protection from disturbance while they have dependent young, even if away from the nest. In locations where these Schedule 1 species are found, these requirements place an additional constraint on the management of aquatic and riparian vegetation.

Example: Managing watercourses with water voles present

Due to a severe decline in numbers in recent decades, water voles and their habitat are fully protected under Schedule 5 of the Wildlife and Countryside Act 1981 (as amended). It is an offence to:

- intentionally kill, injure or take (capture) a water vole
- intentionally or recklessly damage, destroy or obstruct access to any structure or place which water voles use for shelter or protection
- intentionally or recklessly disturb water voles while they are using such a place

Water vole presence is a material consideration when planning the management of aquatic and riparian vegetation. It is essential that any technique selected can be used in a manner that will not result in damage to water vole burrows or disturbance to water voles within their burrows.

The most damaging technique is likely to be the use of a de-weeding bucket to remove in-channel vegetation. Machine operatives may not be able to see where the bucket is placed and scraping of the banks may occur, particularly in deep, narrow channels and if burrows are present these may be damaged. Vegetation cuttings may also block burrows if not placed sufficiently distant from the bank top.

For watercourses less than 1–2 m wide, mechanical methods of management may therefore not be appropriate if water voles are present.

Other management techniques also have the potential to impact upon water voles either directly or indirectly. For example, grazing or reprofiling of banks could result in direct impacts due to damage to burrows. Techniques that use shading to control vegetation can also result in indirect impacts by reducing species of plant that provide food and cover for water voles.

Further information is available from:

- Natural England (www.naturalengland.org.uk/ourwork/regulation/wildlife/species/default.aspx)
- Natural Resources Wales (http://naturalresourceswales.gov.uk/our-work/policy-advice-guidance/protected-species-wales/uk-protected-species/?lang=en)
- *Water Vole Conservation Handbook* (Strachan et al. 2011)

Example: Undertaking management in the vicinity of badger setts

Badger setts can be a regular occurrence in the banks of watercourses, particularly watercourses adjacent to woodlands and/or where the soil is sandy, allowing them to dig easily. Badgers and their setts are protected under the Protection of Badgers Act 1992 which makes it an offence to:

- wilfully kill, injure, take, possess, or cruelly ill-treat a badger
- attempt to interfere with a badger sett by damaging, destroying or obstructing access to a badger sett or disturbing a badger when it is occupying a sett

A badger sett is defined as any structure or place which displays signs indicating current use by a badger.

The management of aquatic and riparian plants could result in interference to a badger sett. For example, tracked excavators and/or tractor mounted flail mowers could inadvertently damage a sett if entrances are located close to the top of the banks where the machines operate from. Cut vegetation may also block sett entrances.

Natural England and Natural Resources Wales/Welsh Government can issue licences to permit interference with a badger sett for the purpose of 'any operation to maintain or improve any existing watercourse or drainage works, or to construct new works required for the drainage of land', which includes the cutting and removal of vegetation.

In July 2013, Natural England introduced a new class licence for IDBs which permits interference with badger setts where there is a need to conduct routine watercourse or drainage maintenance operations, such as vegetation cutting. Only employees or contractors of IDBs are entitled to register to use this licence. Any licence granted will specify conditions required to limit interference.

Further information is available from:

- Natural England (www.naturalengland.org.uk/ourwork/regulation/wildlife/species/)
- Natural Resources Wales (http://naturalresourceswales.gov.uk/apply-buy-report/apply-buy-grid/protected-species-licensing/uk-protected-species-licensing/badger-licences-issued-by-NRW-and-welsh-government/?lang=en)

4.4.3 Notable and/ or rare species

Watercourses may support species that, although not legally protected, are rare or scarce and therefore require consideration such as:

- UK and local Biodiversity Action Plan (BAP) species
- Species of Principal Importance listed under the Natural Environment and Rural Communities (NERC) Act 2006
- National Red Data Book Species

The presence of notable and rare species within or adjacent to the watercourse should be taken into account when planning the management of vegetation. Where possible, management techniques should be chosen that potentially benefit the species and those which could have detrimental impacts should be avoided. For example, controlled grazing and poaching by cattle may benefit greater water parsnip *Sium latifolium* (a UK BAP species) by creating open areas on banks allowing seeds to germinate. However, the planting of trees to create shading is likely to be detrimental as this species cannot tolerate heavy shade.

Guidance should be sought on how to manage vegetation within watercourses containing notable and/ or rare species from the Environment Agency, Natural Resources Wales, Natural England or local wildlife and rivers trusts.

Useful websites for further information

UK BAP priority species:

- JNCC (http://jncc.defra.gov.uk/page-5717)
- List of Species of Principal Importance in England:
- Natural England (www.naturalengland.org.uk/ourwork/conservation/biodiversity/protectandmanage/habsandspeciesimportance.aspx)
- List of Species of Principal Importance in Wales:
- Wales Biodiversity Partnership (www.biodiversitywales.org.uk/en-GB/Section-42-Lists)
- Sources of information to identify whether records of notable and/or rare species are available for a specific watercourse include:
- National Biodiversity Network (NBN) Gateway (https://data.nbn.org.uk)
- Local Environmental Records Centres (www.alerc.org.uk)

4.4.4 Fisheries

Aquatic plants are important for fish, including the European eel, as they promote invertebrate life, provide spawning areas and shelter for fry. Under the Salmon and Freshwater Fisheries Act 1975 it is an offence to wilfully disturb any spawn or spawning fish, or any bed, bank or shallow on which there may be spawn or spawning fish.

The control of aquatic plants is an essential part of managing many fisheries. For example, the cutting of water-crowfoot *Ranunculus* sp. in chalk streams in spring and summer aids channel flow, scours gravels and regulates water levels.

The presence of fish should be taken into account when choosing plant management techniques. Physical techniques have the most potential to disturb spawning fish and, if chosen, should be conducted outside the spawning seasons (generally November to March for salmon and trout, and April to June for coarse fish).

Cut vegetation should also be removed from the watercourse to prevent deoxygenation from decomposing material which can kill fish and invertebrates. Deoxygenation may also occur as a result of chemical control if the treated plants are left to decompose in situ.

Environmental techniques such as channel narrowing to increase flow velocity and fencing to allow bankside vegetation growth may provide benefits for fisheries by reducing siltation and providing habitat and cover.

Further information on aquatic plant management and fisheries

- *Managing River Habitats for Fisheries: A Guide to Best Practice (SEPA, undated)* (http://www.sepa.org.uk/water/water_regulation/regimes/engineering/habitat_enhancement/best_practice_guidance.aspx#Managing)

4.4.5 WFD compliance

The Water Framework Directive (WFD) aims to protect and improve the water environment. River basin management plans (RBMPs) describe how the Water Framework Directive will be achieved in a region. The RBMP sets ecological objectives for each water body and deadlines by when these objectives need to be met. The plans set out, at a local level, which actions and measures will be necessary to achieve the objectives of the Water Framework Directive. These measures may include the sensitive management of aquatic and riparian vegetation and the control of non-native invasive species.

The objective for all water bodies is to achieve good ecological status (GES), which is defined as a slight variation from undisturbed natural conditions. This is measured using biological elements including fish and aquatic vegetation, and supporting elements such as hydromorphology, ammonia and phosphates.

While good ecological status is defined as a slight variation from undisturbed natural conditions in natural water bodies, artificial water bodies (AWBs) and heavily modified water bodies (HMWBs) are unable to achieve natural conditions. These are water bodies that have been altered through human activity, for example, by flood risk management, urbanisation, land drainage or navigation. Instead, AWB/ HMWBs have a target to achieve good ecological potential (GEP), which recognises their important function(s) while making sure ecology is protected as far as possible. It is usually within AWB/ HMWBs that aquatic and riparian plant management is most frequently conducted.

Watercourse management can impact on natural processes and damage important habitats. This can cause the ecology of a water body to deteriorate and prevent environmental improvements from being carried out. Watercourse management can also be beneficial and help to achieve environmental improvements in the river basin, enhancing the water environment.

When undertaking vegetation management it is important to:

- ensure it does not cause the ecology of a water body to deteriorate
- try to undertake environmental improvements to achieve good ecological status or potential

If the activities cause deterioration or prevent ecological objectives from being met then the UK is at risk of being fined by the European Commission. Under section 161AZ of the Water Resources Act 1991 the Environment Agency is also empowered to take enforcement action against anyone who has caused hydromorphological harm to a watercourse; if the works were consented, then enforcement action would be taken against the consenting organisation. Hydromorphological harm could result from inappropriate vegetation management.

WFD assessments

Before undertaking any aquatic and riparian plant management, the ecological and hydromorphological impacts of the management technique to be used will need to be fully screened to establish if the proposed activity will:

- cause deterioration in the ecological status of the water body
- prevent the achievement of ecological objectives
- prevent or enable the environmental improvements which need to be put in place to achieve GES/ GEP

If the management activity causes deterioration or prevents achievement of the ecological objectives then it is necessary to either amend the plans to ensure this does not occur, or carry out a detailed WFD assessment.

In most cases, the management of aquatic and riparian vegetation in AWB/ HMWBs, is unlikely to pose a risk of deterioration or a risk to water body status/ potential, particularly if carried out over short lengths and following best practice guidance. Some management techniques, however, could potentially damage the hydromorphology of certain types of watercourse, for example, de-weeding with a solid bucket or manipulation of channels to alter water levels or flow.

As described more in Chapter 8, the Decision-making Spreadsheet Tool has been developed to help watercourse managers choose the most appropriate management technique, based on its effectiveness to control the given species and the potential damage to a specific type of watercourse, and therefore, in most cases, a detailed WFD assessment should not be necessary.

Consult the Environment Agency or Natural Resources Wales to establish any further assessment requirements and to determine whether a WFD Compliance Assessment needs to be carried out.

Sources of further information

- Introduction to the Water Framework Directive (http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/research/planning/33362.aspx)
- River basin management plans (http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/research/planning/148254.aspx)
- Implementing the WFD and mitigation measures – Healthy Catchments (www.restorerivers.eu/RiverRestoration/Floodriskmanagement/HealthyCatchmentsmanagingforfloodriskWFD/tabid/3098/Default.aspx)

Generally, works undertaken to manage aquatic and riparian plants, such as cutting or spraying with herbicides, do not require any formal Environmental Impact Assessment

(EIA). More intrusive longer-term environmental plant management techniques, for example, modifications to the channel (that is, widening, narrowing, deepening) or the installation of structures to alter flow characteristics, may fall under the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended). Under these regulations drainage bodies (that is, the Environment Agency, IDBs and LLFAs/ local authorities) are required to determine whether such ‘improvement works’ will have a significant impact on the environment.

Land drainage improvement works carried out by drainage bodies are ‘permitted development’ under the Town and Country Planning (General Permitted Development) Order 1995 and are exempt from planning permission. For European designated sites (SACs and SPAs), existing provisions within the Town and Country Planning (General Permitted Development) Order 1995 and the Conservation of Habitats and Species Regulations 2010 (as amended) are designed to ensure that permitted developments likely to have a significant effect on a European site cannot go ahead unless the local planning authority has determined, after consultation with Natural England or Natural Resources Wales, that the development would not affect its integrity.

Although an EIA may not be necessary, it is still important to take environmental considerations into account when planning and carrying out works to manage aquatic and riparian plants. An appropriate level of environmental appraisal should always be undertaken.

Sources of further information

- Notes on the Environmental Impact Assessment (Land Drainage Improvement) Regulations 1999 (http://archive.defra.gov.uk/environment/flooding/documents/policy/guidance/eiaguide1999.pdf)
- The Environmental Impact Assessment (Land Drainage Improvement Works) (Amended) Regulations 2005 (http://archive.defra.gov.uk/environment/flooding/documents/policy/guidance/eia-guidance.pdf)

4.4.7 Health and safety

There are a number of hazards associated with working in, on or near to watercourses.

When planning aquatic plant management operations, it is essential that:

- safe systems of work are in place based on a thorough risk assessment
- operatives and, where used, volunteers, are properly trained and instructed, and provided with appropriate PPE

Risk of drowning

The most obvious hazard is the risk of drowning. When conducting any aquatic plant management activities, whether from within the channel or on the bank, there is a danger that operatives may fall into the water and become at risk of drowning. This may be due to slips or falls, strong currents and, in extreme circumstances, machines falling into the water. Adverse weather (for example, heavy rain, severe winds and icy conditions) is likely to increase the danger and working conditions can change quickly, particularly in times of flood.

Health implications

It is also vital to consider the health implications of working within water. The water may possibly be polluted (for example, when working near sewage discharge points) and there is a risk of contracting leptospirosis (or Weil's disease) from water contaminated by rat urine.

Other health and safety issues

Other health and safety implications that may need to be considered when planning any aquatic and riparian plant management include:

- lone working
- use of tools and machinery
- use of chemicals that is, herbicides (see section 7.4.1)
- working adjacent to highways, railways and other infrastructure
- presence of overhead power lines or buried services
- presence of livestock and other animals
- public safety

Further information on health and safety

- Health and Safety Executive (www.hse.gov.uk)

4.4.8 Biosecurity

A good biosecurity routine is vital when carrying out management activities within watercourses to reduce and minimise the risk of spreading invasive non-native plant species and other harmful organisms/ diseases such as crayfish plague.

The most cost-effective method of managing non-native invasive species is to prevent their spread. Many forms of management result in disturbance and fragmentation, which may result in the spread of the plant. This may result in an offence under Section 14 of the Wildlife and Countryside Act 1981 (as amended).

All those carrying out aquatic and riparian plant management should follow the steps of the 'Check, Clean, Dry' campaign (http://www.nonnativespecies.org/checkcleandry/index.cfm).

- Inspect and clean clothing and equipment thoroughly before and after use.
- Avoid areas containing non-native invasive species that are not intended for management to reduce contamination.
- Dry equipment thoroughly for at least 48 hours before reusing it.
- Deploy stop-nets/ booms to collect plant fragments, which should be disposed of safely.

In some instances disinfecting may also be appropriate, for example, when moving from watercourses where signal crayfish are present to catchments where native white-clawed crayfish occur.

Watercourse managers should be able to recognise the most important non-native invasive species and the propagules that cause their spread.

Some of the most problematic non-native invasive species can be recorded on the free PlantTracker (http://naturelocator.org/planttracker.html) and AquaInvaders (http://naturelocator.org/aquainvaders.html) apps developed by the Nature Locator Project team at University of Bristol for iPhone and Android devices.

4.4.9 Waste management

The management of aquatic and riparian plants, particularly by physical techniques, may create waste which requires disposal.

Under the Environmental Permitting Regulations (England and Wales) 2010 (as amended) it is necessary to either register for an exemption or apply for a permit for waste operations. The Environment Agency (in England) and Natural Resources Wales (in Wales) are responsible for issuing permits and exemptions. Registration is free and can be completed online (https://www.gov.uk/get-an-environmental-permit).

Table 4.24.2 details the exemptions relating to the spreading of waste plant material on land and the depositing of dredging spoil that are most likely to be applicable to the management of vegetation within and adjacent to watercourses. A number of other exemptions that may apply are also listed.

Table 4.2 Relevant exemptions

	Exemption	Description
Vegetation/dredging spoil	U13 – Spreading of plant matter to confer benefit	Allows for the spreading of non-hazardous plant matter strimmed from the banks of the watercourse where it has been cut. It only allows for spreading of plant matter at the place of production where benefit is conferred. Up to 50 tonnes per hectare in any 12-month period can be spread.
	U10 – Spreading waste on agricultural land to confer benefit	Allows for the spreading of non-hazardous dredging spoil generated from the creation or maintenance of habitats, ditches or ponds within parks, gardens, fields and forests, on agricultural land. A maximum of 150 tonnes of spoil per hectare can be spread over a 12-month period. It must be spread adjacent to the place from which it was dredged and confer benefit.
	U11 – Spreading waste on non-agricultural land to confer benefit	Allows for the spreading of non-hazardous dredgings from the creation or maintenance of habitats, ditches or ponds within parks, gardens, fields and forests, on non-agricultural land. The waste must be spread adjacent to the place from which it was dredged and confer benefit.
	D1 – Deposit of waste from dredging of inland waters	Allows for the deposit of non-hazardous dredging spoil (dredgings, which also includes plant matter) on the banks of the waters it was dredged from. It also allows for treatment of it by screening and dewatering. Over any 12-month period, the depositing or treating of up to 50 m^3 of dredgings for each metre of land on which waste is deposited is allowed. The waste must be deposited at the closest possible point to where it was dredged from; either

	Exemption	Description
		on the bank of, or on land adjoining, the water it was dredged from, as long as it can be deposited on that land by mechanical means in one operation. It is not permitted to deposit dredged material onto a bank and then move it further away by the same or another machine.
Other	T23 – Aerobic composting and associated prior treatment	Allows for the composting of small volumes of vegetation to produce a compost that can be spread on land to provide benefit.
	T25 – Anaerobic digestion at premises not used for agriculture and burning of resultant biogas	Allows the treatment of plant tissue waste and other biodegradable wastes by anaerobic digestion to produce a digestate which can be used to provide benefit to land. The gas produced must be used for generating energy.
	D7 – Burning waste in the open	Allows for the burning of plant tissue and untreated wood wastes in the open. Waste can only be burnt at the place where it was produced.

Additionally, if cut vegetation is not removed from the water, the disposal of this within water becomes a water discharge activity and requires an environmental permit or the registering of an exemption.

If waste has to be removed from site, it must be taken by a licensed waste carrier and go to a suitably authorised landfill site, particularly if it contains non-native invasive species.

Sources of further information about waste exemptions

- Waste exemptions (www.gov.uk/waste-exemptions-disposing-of-waste)
- Registration of exemptions to discharge to surface and groundwaters (http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/business/topics/water/117481.aspx)
- Waste exemptions (in Wales) (http://naturalresourceswales.gov.uk/apply-buy-report/apply-buy-grid/waste/waste-permtting/exemptions/?lang=en)

4.4.10 Hydraulic impact

When carrying out management of channel and bankside vegetation it is important to be aware of the impact this has on hydraulic roughness and flow conveyance, and the potential impact of this change.

The possible hydraulic impacts of reducing vegetation cover are:

- a more hydraulically efficient channel with an overall lower hydraulic roughness
- an increase in velocity resulting in a reduction in water level for a given flow
- an increase in the channel capacity at the site that may convey more floodwater downstream (may also affect the timing of the hydrological response as a result of the local increase in velocity and flood peaks may arrive earlier)

- increasing likelihood for sediment transport as a result of vegetation removal (that helps stabilise the bed and banks) and an increase in velocity

There are circumstances where an increase in flow downstream may increase flood risk. Depending on the nature of the changes and the catchment characteristics, this may warrant further investigation before beginning vegetation management.

When making an initial assessment of the potential impact on flood conveyance, consider whether the watercourse and catchment is likely to be sensitive to a change in flow conveyance and if there are any key receptors downstream. The assessment should primarily consider the downstream land use on the floodplain and the receptors that may at risk as a result of an increase in downstream flow. Further investigation may be required if there are communities or urban areas downstream that are either in close proximity to the watercourse or are known to be at risk of flooding.

The following other influencing factors may need to be considered.

- **Size and nature of the watercourse.** The hydraulic impacts of vegetation are likely to be most critical for small watercourses that have a limited capacity.
- **Distance and/ or change in catchment area downstream.** When considering downstream implications, the distance downstream and the change in catchment area should also be considered. It is expected that the impact of upstream change will dilute with distance downstream and increasing catchment area and therefore the change in flow may become negligible over large distances. If available, the Flood Estimation Handbook (FEH) CD-ROM can be used with Ordnance Survey (OS) mapping to estimate the change in catchment area and distance.
- **Existing flood risk within the catchment.** Inspection of the Environment Agency's flood maps (https://www.gov.uk/check-if-youre-at-risk-of-flooding) will identify areas of flood risk downstream that could be exacerbated by changes upstream.
- **Seasonal implications.** This should consider the impact of vegetation (and the potential impact of management) during the summer months between July and September when vegetation growth will be at its peak. The impact on conveyance and downstream flows is expected to be at its greatest during these months.

Appendix B summarises how further assessment, using the Conveyance Estimation System (CES), can be made. The CES is a tool which allows the detailed incorporation of vegetation into conveyance estimates.

4.4.11 Consenting requirements/ permissions/ agreements

Flood defence/ land drainage consent

Activities carried out to manage vegetation within and on the banks of watercourses are unlikely to require consent from the Environment Agency/ Natural Resources Wales if the watercourse is a Main River, or the IDB/ LLFA if it is an Ordinary Watercourse. Exceptions are:

- de-weeding with a solid bucket which removes plants and their roots from a Main River
- management techniques that result in physical modifications to the channel or banks (for example, deepening and widening, to alter flow rates and water depth)
- installation of structures to alter flow rates and water depth

The Environment Agency, IDBs and LLFAs also have flood defence/ land drainage byelaws which require persons to obtain consent for certain activities within a specified distance of a Main River or Ordinary Watercourse (typically 8 or 9 m, but can be greater). These byelaws vary between Environment Agency regions and IDBs/ LLFAs, but include activities such as the planting of trees, erection of fences and alteration of flow, which may be considered as part of vegetation management techniques.

Before undertaking any works on a Main River or Ordinary Watercourse, whether consent is required or not, it is recommended that advice is sought from the appropriate authority.

Sources of further information

Flood defence consent:

- Apply for a flood defence consent (in England) (https://www.gov.uk/flood-defence-consent-england-wales)
- Flood defence consent (in Wales) (http://naturalresourceswales.gov.uk/apply-buy-report/apply-buy-grid/flood-defense/?lang=en)
- Details for IDBs and LLFAs:
- Association of Drainage Authorities (www.ada.org.uk)
- Local Government Flood Risk Portal (www.local.gov.uk/floodportal)
- Rights and responsibilities of those owning land or property next to a river, stream or ditch:
- *Living on the Edge* (www.gov.uk/government/publications/riverside-ownership-rights-and-responsibilities)

Agreement to use herbicides in or near water

All management of aquatic and riparian vegetation using herbicides requires agreement from the Environment Agency/ Natural Resources Wales. To obtain agreement it is necessary to complete an application form and to supply a range of information including:

- details on the site
- the problem species
- any nature conservation sites
- downstream users and abstractors
- fish presence
- details of the herbicide to be used and how it will be applied

Anyone who uses herbicides in or near water must have the necessary skills, knowledge and qualifications. They must hold a relevant National Proficiency Test Certificate (NPTC) of competence, which must be supplied with the application. The NPTC must be for applying herbicides in or near water.

Further information on the use of herbicides in or near water can be found in section 7.4.1.

Guidance and the application forms

- Application to use herbicides in or near water (https://www.gov.uk/government/publications/application-to-use-herbicides-in-or-near-water)
- Natural Resources Wales – using herbicides (http://naturalresourceswales.gov.uk/apply-buy-report/apply-buy-grid/water/using-herbicides/?lang=en)

4.4.12 Partnership working

A watercourse can have numerous functions and consequently a number of parties and individuals interested in its management. Interested parties may include:

- Environment Agency
- Natural Resources Wales
- IDBs
- LLFAs/ local authorities
- Canal & River Trust
- wildlife trusts
- angling trusts
- Natural England
- RSPB
- local interest groups
- landowners/ tenants

Management needs to ensure that the needs of the greatest number of watercourse users can be met. However, having a number of parties and individuals interested in watercourse management provides significant opportunities for partnership working. Partnership working can be of benefit by:

- allowing knowledge to be shared in relation to a specific watercourse and/ or catchment
- providing opportunity for volunteer involvement which can reduce costs
- providing opportunity for collaborative working and cost sharing
- promoting more unusual, long-term management strategies (for example, tree planting to create shading, buffer strips) which may not be possible to implement by one operating authority working in isolation
- allowing watercourse management to be integrated into larger-scale land management initiatives with wider environmental benefits (for example, diffuse pollution management schemes)

Example: The Return of the Natives project, Dorset

The Return of the Natives (ROTN), which was launched in 2009, is a partnership project between:

- Dorset Farming & Wildlife Advisory Group South West
- Dorset Wildlife Trust
- Natural England
- Environment Agency
- Dorset Area of Outstanding Natural Beauty (AONB)

The project involves mapping the distribution of non-native invasive species and providing targeted advice and assistance in their management.

The partnership is registered as a 'Local Action Group', with the aim of addressing the spread of non-native invasive plant species in key river catchments in Dorset. Initial funding for the project came from the Non Native Species Secretariat (NNSS), Natural England and the Environment Agency, with current funding provided by NNSS, the Environment Agency, Dorset Wildlife Trust and the Dorset AONB. ROTN has become a delivery partnership of organisations, landowners and local communities, with one part-time officer based at the Dorset Wildlife Trust facilitating delivery.

The partnership focuses on the Char and its tributary the Catherson Brook where giant hogweed *Heracleum mantegazziannum* and Himalayan balsam *Impatiens glandulifera* are an issue; the Frome catchment (mainly the River Hooke) where Himalayan balsam is problematic; and the Bere Stream (a tributary of the River Piddle) where Himalayan balsam is again a concern.

The partnership has achieved considerable success. For example, on the River Hooke, while Himalayan balsam has not been completely eradicated, five hectares of wet woodlands, fens and floodplains have been cleared of this species and native species have started to return to bankside habitats. Much of this has been achieved through groups of volunteers hand-pulling and bagging the plant, which is then removed and disposed of by the landowner.

4.4.13 Catchment-scale approach

When planning and carrying out aquatic and riparian vegetation management it is vital to place the watercourse where work is proposed within the context of the wider catchment. Managing vegetation at a specific location may not result in effective control if the wider catchment is not considered.

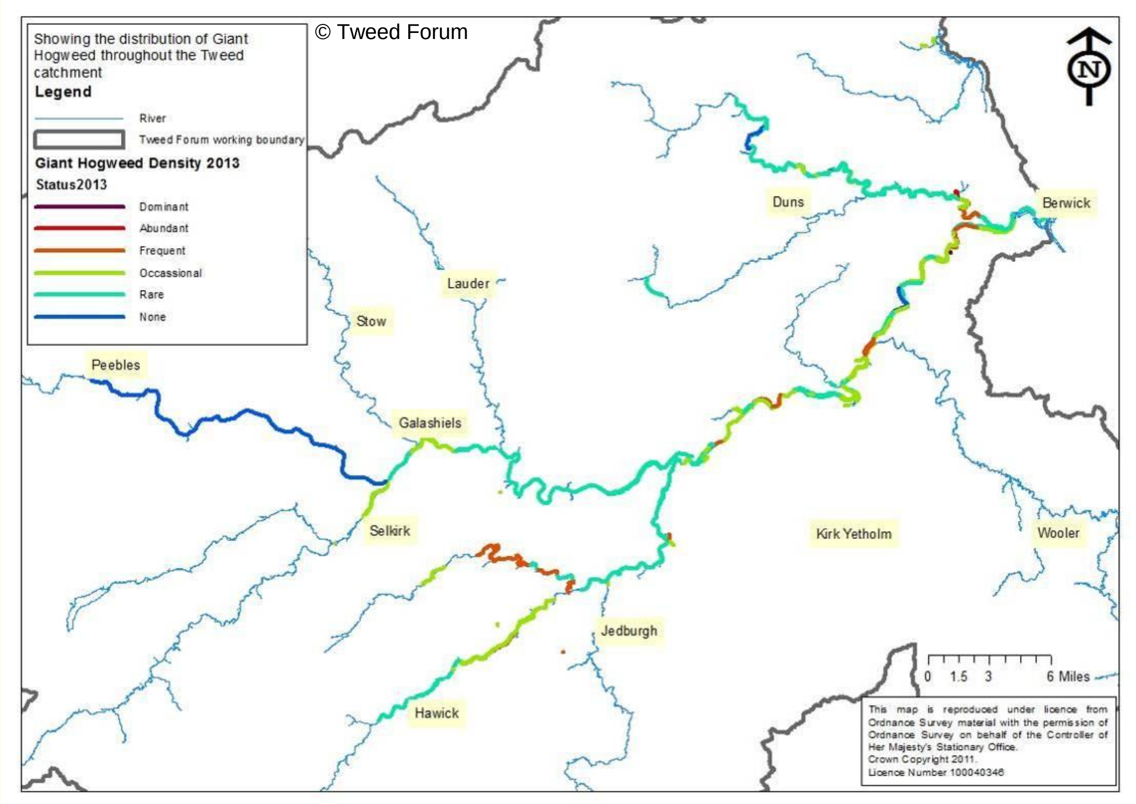
This is particularly important when considering non-native invasive species as many are readily dispersed along watercourses. Undertaking management at an isolated specific location may not be successful if a stand is present upstream. The upstream location will provide a continual source of seeds and vegetative material for recolonisation and long-term eradication is unlikely to be successful.

Example: Giant hogweed in the River Tweed catchment

The River Tweed and its tributaries are designated as a SAC and SSSI. Giant hogweed *Heracleum mantegaziannum* was first identified as an issue in the Tweed catchment in the 1980s. Sporadic and localised control attempts were made but by 2002 giant hogweed was present on over 300 miles of river bank. Therefore, the Tweed Forum embarked on the Tweed Invasives Project to control giant hogweed along with other non-native invasive species within the Tweed catchment.

The initial stages of the project involved a comprehensive survey to ascertain the extent of the problem and consultation with stakeholders. A management strategy was then developed which took a holistic approach and covered the entire 3,080 square miles of the Tweed catchment, including both the Scottish and English sections. The focus of control efforts was to work from the uppermost infested areas within the catchment, working downstream.

The project has now run for 11 years and the majority of the Tweed is now classed as having only 'occasional' or 'rare' densities of hogweed, though there are still occasional stretches that are described as having 'frequent' densities.



Similarly, the management of problematic native vegetation should also be placed within the wider catchment context. For example, carrying out management on a section of watercourse upstream of a section that is not maintained may not result in the desired outcome in terms of flow and reduced flood risk in the downstream section; flows will remain impeded in the downstream section. Water from the managed section may then not be able to discharge into the unmanaged section as quickly or effectively as required, resulting in flooding or waterlogging.

Adopting a catchment-scale approach to vegetation management is recommended.

4.5 Management objectives

Where a problem is identified that requires management, it is important to have a clear objective. This objective should be linked to the function(s) of the watercourse.

For example, a watercourse to be managed for flood risk management purposes may require a different intensity and type of management to a watercourse being managed for fisheries. In the first case, it is likely that a relatively wide central channel will need to be kept clear so that flows are not impeded and channel capacity is maintained. In the second case, only short sections of vegetation are likely to require clearance to create some open areas for angling and a range of habitats for fish.

In the case of non-native invasive species, complete eradication may be the management objective, whereas in the case of problematic native species the objective should never be for complete eradication; selective management should be the goal.

In some situations management may have more than one objective.

Once the need and objectives for management have been determined, the most appropriate technique for management can be selected (Chapters 7 and 8) and a management plan devised, including an appropriate monitoring programme (Chapter 10).

4.6 Management plan

All aquatic and riparian vegetation management operations should follow a long-term management plan that identifies:

- the objective(s) of the management
- the proposed management measures
- the risks associated with them

Having such a plan will ensure there is continuity and stability of management.

The management plan may need to be agreed with statutory agencies, especially where conservation areas such as SACs, SPAs and/ or SSSIs may be affected. It should take account of:

- statutory and non-statutory nature conservation sites that may be affected
- protected and rare species present (for example, breeding birds, rare plants, water vole *Arvicola amphibius* and so on)
- WFD targets that need to be met
- standard of service required (total control, partial, periodic)

- target vegetation identified to species level, as well as non-target plants
- management methods and timing (based on target species)
- details of monitoring and review to judge the success/ failure of approach and revise for better results (Chapter 10)

It is important to bring together all parties and individuals interested in the management of the watercourse to develop a management plan that meets the requirements of the greatest number of users.

In most cases, where the function(s) of the watercourse is impaired sufficiently to require management, the management plan will consider techniques that operate over short and medium-term timescales so that the function(s) can be maintained/ restored relatively quickly.

Consider techniques that act over longer timescales, such as nutrient management or the planting of trees to increase shading, so that the problems created by aquatic and riparian vegetation are reduced in the future. Considering longer term options for vegetation management on a catchment scale will bring the greatest benefits.

5. Species

5.1 Introduction

A wide range of aquatic and riparian plant species may require management in Great Britain, including both native and non-native species. This chapter discusses a number of species that can become problematic in a range of different watercourse types. For each species the following information is provided:

- identification features and ecology
- key problems caused
- species-specific issues (for example, non-native invasive species, toxicity and waste disposal)
- appropriate and inappropriate control techniques

Accurate identification is crucial to distinguish plants from other, sometimes similar, species. This is because the growth form, means of spread and other ecological characteristics all influence the most effective means of control.

In addition, it is important to understand the legal status of the habitats and vegetation present so that activities can be modified accordingly. For example, it is prohibited in law to cause plants listed in Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) to spread into the wild, some plants are protected or rare and could be adversely impacted upon by management, and some rivers are designated as SAC/ SSSI due to the vegetation communities present (see the legislative review in Appendix A for details).

Useful identification guides

- *British Water Plants* (Haslam et al. 1982)
- *The Wildflower Key* (Rose 2006)
- *New Flora of the British Isles* (Stace 2010)
- *The Vegetative Key to the British Flora* (Poland and Clement 2009)
- The Plant Crib (BSBI 2013)
- *Sedges of the British Isles* (Jermy et al. 2007)
- *Pondweeds of Great Britain and Ireland* (Preston 2003)
- *Water Starworts: Callitriche of Europe* (Lansdown 2009)

Although it is considered important that the problem species is specifically identified, it is recognised that, for some species, the expertise to do so may not be available. This technical guide also provides guidance on managing species groups based on growth habit as detailed in Table 2.1. The field guide provides concise species descriptions to help with identification while on site.

5.2 Submerged species

Submerged plants can cause many problems in watercourses, particularly through impeding flows, as well as affecting fisheries and other recreational activities such as boating. They also provide valuable habitats for wildlife, particularly as breeding, feeding and refuge sites for fish and invertebrates.

Growth forms of submerged species are variable and can range from strap-shaped leaves to fine feathery fronds. Roots of submerged species are often weak and easily dislodged, and plants can usually regenerate from fragments; this is a key factor when selecting an appropriate management technique. Most species die back in autumn and over-winter as rhizomes, seeds, turions, tubers, or as short shoots ready to grow in spring.

Submerged plants affect the oxygen content of the water, being net contributors during spring and summer, but absorbing more than they produce as they die back later in the year or following vegetation control operations such as cutting. The impact on the oxygen content of water is therefore a key consideration for the management of submerged species.

Problematic submerged aquatic species discussed below include:

- native water-milfoils *Myriophyllum* spp.
- parrot's-feather *Myriophyllum aquaticum*
- submerged pondweeds *Potamogeton* spp.
- water-crowfoots *Ranunculus* spp.
- rigid hornwort *Ceratophyllum demersum*
- mare's-tail *Hippuris vulgaris*
- Canadian waterweed *Elodea canadensis* and Nuttall's waterweed *Elodea nuttallii*
- curly water-thyme *Lagarosiphon major*

Some water-crowfoot *Ranunculus* species can also have a floating leaves and could be discussed in section 5.4, but those which tend to require management generally have a submerged growth habit and this group of species is discussed in this section.

5.2.1 Water-milfoils *Myriophyllum* spp.

There are a number of native water-milfoil *Myriophyllum* species in the UK:

- spiked water-milfoil *Myriophyllum spicatum*
- whorled water-milfoil *Myriophyllum verticillatum*
- alternate water-milfoil *Myriophyllum alternifolium*

All species have feathery leaves arranged in whorls around a circular stem. The table below summarises the key features of each. The vegetative characteristics, particularly the number of leaves and leaf segments can vary, particularly when growing on mud or in stressed conditions and this should be taken into account when identifying species.

Spiked water-milfoil *Myriophyllum spicatum*
© JBA Consulting

Spiked water-milfoil *Myriophyllum spicatum*	Whorled water-milfoil *Myriophyllum verticillatum*	Alternate water-milfoil *Myriophyllum alternifolium*
3–5 leaves with 13–38 segments	4–6 leaves with 24–35 segments, sometimes emerging from the water	3–4 leaves with 6–18 segments
Base-rich ponds, lakes and slow-flowing rivers and ditches, mostly in lowlands	Base-rich ponds, lakes, canals and slow-flowing rivers in lowlands	Base-poor lakes, ponds, slow streams and ditches, often in upland areas
Often has a reddish tinge	Generally light green in colour	
Flowers in whorls	Flowers in whorls	Upper flowers are alternate
Reproduces by seed and vegetative growth	Reproduces by turions produced in September to November. These over-winter on the bed until February.	
Tolerant of eutrophic and brackish waters		A species of nutrient-poor waters
Common throughout UK and often requires management	Scattered distribution and rarely needs management	Locally frequent and scarce and rarely needs management

Key problems caused

- Can form dense infestations which impede flow.
- Dense infestations can adversely affect angling and navigation.
- Alternate water-milfoil *Myriophyllum alternifolium* is scarce – **check species identification and consider the need for management**.

Spiked water-milfoil *Myriophyllum spicatum* © JBA Consulting

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques can be effective, but only have a short-term impact. De-weeding with a solid bucket has a longer term impact as turions are removed.	Mid July to September	7.3 7.3.4
Chemical	None available	n/a	n/a
Environmental	Water-milfoils *Myriophyllum* spp. are poorly tolerant of shade and can be controlled through a number of shading methods	n/a	7.5.1 7.5.2
Biological	Common carp *Cyprinus carpio*, and other bottom feeding fish, create turbid water which can help to reduce regrowth of these species.	n/a	7.6.3
Novel	Hydro Venturi can be effective on water-milfoils *Myriophyllum* spp.	n/a	7.7.4

5.2.2 Parrot's-feather *Myriophyllum aquaticum*

Parrot's-feather *Myriophyllum aquaticum*

Parrot's-feather *Myriophyllum aquaticum* is a non-native invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended). It is an offence to plant or cause its spread in the wild.

It was first recorded in the wild in Britain in 1960. It is a common aquarium plant which has become established in the wild from discarded plant material. It is now predominantly found in ponds, but also canals, rivers and lakes, reservoirs and ditches throughout the UK. It is most often found in eutrophic waters.

Like all water-milfoil *Myriophyllum* species it has feathery leaves which are arranged around the stem in whorls, usually of 4–6, with 8–30 segments. In contrast to the native members of this group (see section 5.2.1), Parrot's-feather *Myriophyllum aquaticum* is readily able to grow on land when ponds dry out and could also be considered as an emergent species, producing feathery shoots in addition to the submerged leaves. Its leaves have dense stalkless glands which give the emergent leaves a blue-grey colour.

Only female plants are established in the UK, so spread is vegetative from small fragments of plant. The plant is brittle and so fragments easily, which can result in the spread of this species. This should be considered when devising management plans.

Key problems caused

- Forms dense, single species stands which out-compete native species for light and nutrients.
- Can form dense infestations which impede flows.
- Dense infestations adversely affect angling and navigation.

Parrot's-feather *Myriophyllum aquaticum*

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective on large infestations, but great care must be taken to reduce the downstream spread of plant fragments.	Mid July to September	7.3
Chemical	Glyphosate-based herbicide applications on emergent growth can be effective. This technique cannot be used on submerged growth. The use of an adjuvant is recommended. It is likely that two applications per year and regular annual treatment will be necessary.	March to October	7.4.1
Environmental	This species is intolerant of fast-flowing waters and increasing flows on slow-flowing channels may help reduce infestations. It is intolerant of shade and can be controlled through a number of shading methods. As it is a species common in eutrophic waters, reducing nutrient loadings, through a number of methods, can be an effective long-term strategy to reduce growth.	n/a n/a n/a	7.5.5 7.5.1 7.5.2 7.5.6
Biological	None currently available	n/a	n/a
Novel	None recommended	n/a	n/a
Integrated	Physical techniques, used in conjunction with chemical control of emergent re-growth, can be an effective method of control.	As above	7.8

Other non-native water-milfoil Myriophyllum species have previously been recorded in the UK including:

- two-leaf water-milfoil *M. heterophyllum*
- red water-milfoil *M. verrucosum*

In the light of changing climate and other possible garden escapes/ releases, these species may become problematic in the future and require control.

Stout water-milfoil *Myriophyllum robustum* is another water-milfoil species not yet recorded in the UK that could also become problematic. It is considered that appropriate techniques to control parrot's-feather *Myriophyllum aquaticum* would also be applicable to these other non-native water-milfoil *Myriophyllum* species.

5.2.3 Submerged pondweeds *Potamogeton* spp.

Fennel pondweed *Potamogeton pectinatus*

The true pondweeds *Potamogeton* spp. are a group of 21 native species, plus a number of hybrids. A large number of these pondweeds *Potamogeton* spp. have an entirely submerged growth habit, whereas others (discussed in section 5.4.1) have floating leaves.

Some of the submerged pondweeds *Potamogeton* spp. are common, whereas others are rare or localised in occurrence (for example, grass wrack pondweed *Potamogeton compressus,* sharp-leaved pondweed *P. acutifolius*). **Care should be taken to accurately identify the species prior to management** (see section 5.1).

It is generally only certain species of submerged pondweed *Potamogeton* spp. that are problematic and often only in certain situations. Problematic submerged pondweed *Potamogeton* species of greatest concern are usually:

- curled pondweed *Potamogeton crispus*
- fennel pondweed *Potamogeton pectinatus*

On rare occasions small pondweed *P. bechtoldii,* perfoliate pondweed *P. perfoliatus* and lesser pondweed *P. pusillus* can be problematic. Broad-leaved pondweed *P. natans* is discussed in section 5.4.1 with the floating-leaved species.

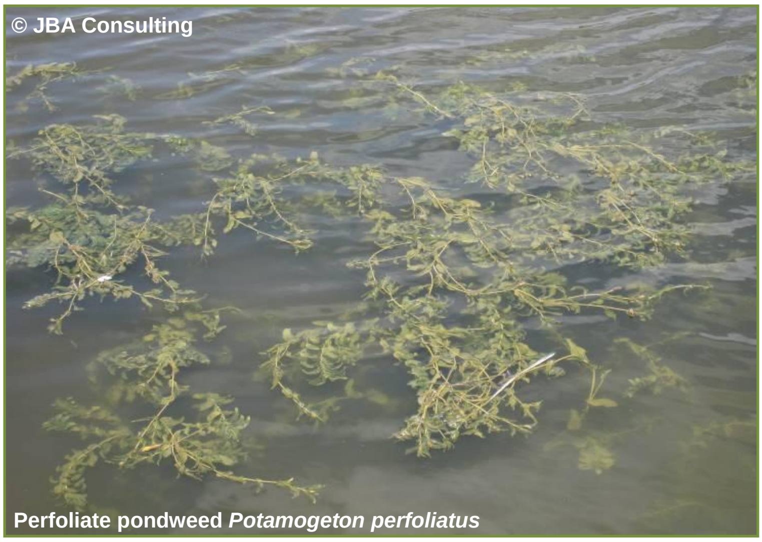
The species which usually creates the biggest problems, fennel pondweed *Potamogeton pectinatus*, is a submerged pondweed with fine leaves. It grows from a creeping stolon rooted in the sediment of still or slow-flowing water bodies. Reproduction can be vegetative, or by turions which drop off into the sediment to grow the following spring. It is strongly associated with organic pollution and is an aggressive coloniser which can out-compete most other plant species.

Curled pondweed *Potamogeton crispus*, another problematic species, grows from creeping rhizomes and has leaves with a characteristic curled shape and a finely serrated edge. It grows in still and fast-flowing water and can tolerate a wide range of nutrient levels. It can grow in waters of 0.5–2 m deep.

Key problems caused

- It can form dense, single species stands which out-compete other species.
- Dense stands can impede flows.
- Dense infestations can interfere with recreation and navigation.

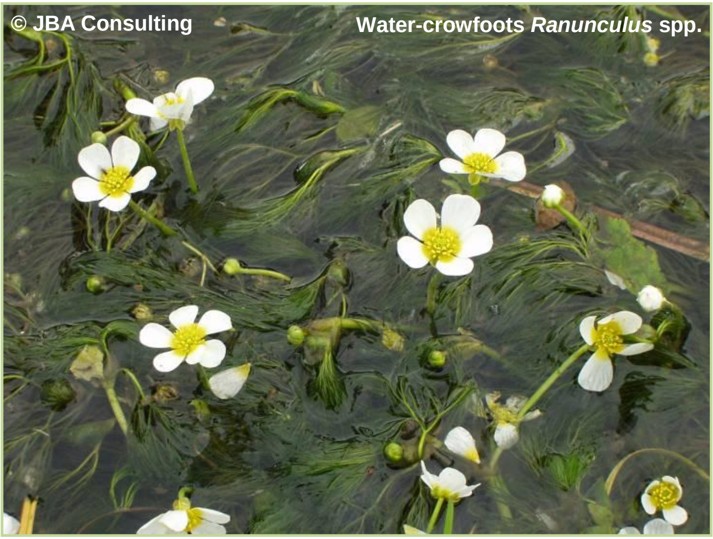
Technique type	Applicability	Timing	Relevant sections
Physical	Submerged pondweeds *Potamogeton* spp. respond well to physical techniques, though there is often only a short-term impact. Regrowth is often rapid and annual cutting can be tolerated. De-weeding with a solid bucket has a longer-term effect through removal of turions.	Mid July to September	7.3 7.3.4
Chemical	None available	n/a	n/a
Environmental	Submerged pondweeds *Potamogeton* spp. are intolerant of shade and can be controlled through a number of shading methods.	n/a	7.5.1 7.5.2
Biological	Common carp *Cyprinus carpio* and other bottom feeding fish create turbid water which can help to reduce regrowth of these species.	n/a	7.6.3
Novel	None recommended	n/a	n/a



Perfoliate pondweed *Potamogeton perfoliatus*

5.2.4 Water-crowfoots *Ranunculus* spp.

There are many species of aquatic water-crowfoot *Ranunculus* spp. in Britain, with several associated with flowing waters of varying speeds and others typical of more slowly flowing and stagnant waters. They are a variable group of species and can be difficult to identify. All species have white flowers with a yellow base to the petals. These petals can vary in size from approximately 2 mm on the smallest flowered species to 15 mm on the largest.



© JBA Consulting Water-crowfoots *Ranunculus* spp.

Water-crowfoot *Ranunculus* species can either have submerged, finely divided (capillary) leaves or broad, floating (laminar) leaves, or a combination of the two. In the capillary leaves, the leaf initially divides into three, with potentially further divisions nearer the leaf tip depending on the species. Almost all species typical of flowing waters have these capillary leaves. Where laminar leaves are present, these are usually lobed to varying extents and shapes, depending on the species.

Growth typically commences early in the season, and dense water-crowfoot *Ranunculus* spp. beds form rapidly. After flowering, the plant dies back leaving short fronds over-winter which then regrow in spring.

Those species of fast-flowing rivers and streams are generally considered the most problematic. However, they do provide valuable habitat for invertebrates, which are important for fisheries. **The need for management of these species should be carefully considered.**

Stream water-crowfoot *Ranunculus pencillatus* © JBA Consulting

These species are often a key component of an important watercourse habitat type, listed on Annex I of the Habitats Directive. The presence of communities containing these species has led to certain rivers being designated as SACs. Management of water-crowfoot *Ranunculus* species must take this into account and liaison with Natural England or Natural Resources Wales should be conducted, where necessary.

Key problems caused

- These species can form dense beds in chalk streams which support valued trout and salmon fisheries and, where present, angling activities can be impaired. However, the presence of water-crowfoot *Ranunculus* species is often vitally important for the fish populations.
- Dense beds can result in silt deposition.
- Dense beds interfere with boating activities.
- They can impede flows and reduce channel capacity.

Technique type	Applicability	Timing	Relevant sections
Physical	Management of water-crowfoots *Ranunculus* spp. is traditionally done through physical techniques, such as cutting. This is a short-term solution and rapid regrowth often means several cuts a year are required. Cutting in the autumn should reduce regrowth within the same year and may also reduce regrowth the following season. Cutting may synchronise regrowth so that peak biomass is achieved simultaneously, causing more severe problems; partial and rotational cutting methods should be considered. With water-crowfoot *Ranunculus* species, not cutting may result in the biomass regrowth each year naturally declining so that future control may not be necessary.	Mid July to September Autumn	7.3
Chemical	None available (significant proportions of the plant are submerged).	n/a	n/a
Environmental	Shading, through a variety of techniques, should help to limit growth of these species. Depending on the species, manipulation of flow characteristics to make it unsuitable for the species present may help in their control.	n/a n/a	7.5.1 7.5.2 7.5.5
Biological	In shallow, hard-bottomed streams cattle will graze on water-crowfoot *Ranunculus* species. The trampling action of cattle will also suppress growth.	n/a	7.6.1
Novel	None recommended	n/a	n/a

5.2.5 Rigid hornwort *Ceratophyllum demersum*

Rigid hornwort *Ceratophyllum demersum* is a wholly submerged aquatic perennial species. It has leaves which are arranged in whorls of usually 6–8, which regularly fork 1–2 times. The leaves are also toothed and the plant has a stiff, rigid structure. It can be found in still and slow-flowing waters of canals, ditches and rivers, and also ponds. It tends to be found in eutrophic to mesotrophic waters, up to 1 m in depth, although sometimes deeper. It is generally dark green in colour and does not root in the watercourse substrate; it is free-floating within the water column.

It can be confused with soft hornwort *Ceratophyllum submersum*, which is a much softer plant with leaves that are forked 3–4 times, with fewer teeth. When young or growing in shade, rigid hornwort *Ceratophyllum demersum* can be quite soft and resemble soft hornwort *C. submersum*. Soft hornwort is a much rarer species, often of coastal areas, which should not be managed. **Care should be taken to accurately identify the species prior to management**.

Key problems caused

- This species can form dense, single-species infestations which impede flows.
- Dense infestations can adversely affect angling and navigation.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, particularly using harvesters and weed buckets which collect the free-floating material, are effective. Being free-floating, other cutting methods are generally not very effective if cut material is not removed.	Mid July to September	7.3.2 7.3.3
Chemical	None available	n/a	n/a
Environmental	Whilst shading, through a variety of methods, is usually a good technique for submerged species, Rigid Hornwort *Ceratophyllum demersum* can grow in low light. Very dense shade of a long duration (up to 6 months) would be needed.	n/a	7.5.2
Biological	Common Carp *Cyprinus carpio*, and other bottom feeding fish, create turbid water which can help to reduce regrowth.	n/a	7.6.3
Novel	None recommended	n/a	n/a

5.2.6 Mare’s-tail *Hippuris vulgaris*

Mare’s-tail *Hippuris vulgaris*

Mare’s-tail *Hippuris vulgaris* is a native aquatic species that can have both trailing submerged leaves and erect emergent leaves. It can grow in waters of up to 3 m deep and can also survive on mud.

Mare’s-tail has a thick spongy stem due to the air cavities within it. Around the stem are short, linear leaves arranged in whorls of 6–12. The tip of the leaf is very rounded. When submerged the leaves tend to be longer and softer, and the whorls more closely grouped. When emergent, the leaves tend to be shorter and stiffer, with the spacing between the whorls greater. The trigger for development of emergent shoots is believed to be high light intensity and warmer temperatures (above 10ºC).

In flower, it has very small, green flowers without petals that form where the leaves join the stem on the emergent parts of the plant. This species can reproduce both from seed and vegetatively, expanding and maintaining stands of this species.

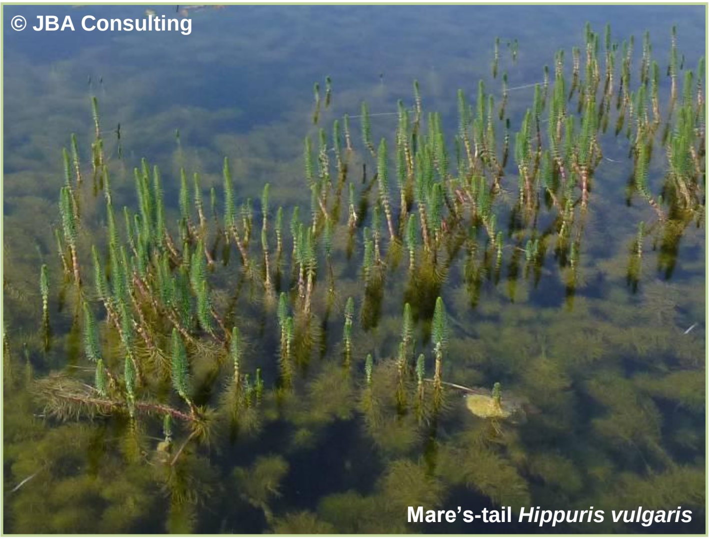
It is a species found in slow to moderately flowing lowland watercourses, and also lakes and ponds. It is usually found in calcareous environments, with eutrophic to mesotrophic conditions.

Key problems caused

- This species can form dense, single-species stands which impede flows.
- Dense stands/growths can adversely affect angling and navigation.

Mare’s-tail *Hippuris vulgaris*

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, using a variety of methods, can be effective in controlling this species. This usually only offers short-term control (one season only and sometimes less than this if undertaken early in the year). Regrowth is usually rapid during the growing season and a repeat cut may be required if cut early in the year (that is, before July).	Mid July-September	7.3
Chemical	None available	n/a	n/a
Environmental	Shading is **not** effective on this species as this species will just spread to the edge of the shaded area. As a species of eutrophic and mesotrophic waters, limiting nutrient inputs may help to reduce the extent of growth.	n/a n/a	 7.5.6
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a



Mare's-tail *Hippuris vulgaris*

5.2.7 Canadian waterweed *Elodea canadensis* and Nuttall's waterweed *Elodea nuttallii*

Canadian waterweed *Elodea canadensis* and Nuttall's waterweed *E. nuttallii* are species native to North America that have naturalised in the UK since being recorded in 1836 and 1966 respectively. They are commonly sold as oxygenating plants by the horticultural trade and are species of slow-flowing and stagnant water.

These species grow from stolons rooted in the sediments at the bottom of watercourses and have dark green translucent leaves in whorls of three (occasionally four). The key differences between the two species are summarised in the table below.

Canadian waterweed *Elodea canadensis*	Nuttall's waterweed *Elodea nuttallii*
Broad leaves, widest at the middle	Narrower leaves, widest at the base
Leaf tip is blunt	Leaves taper to a pointed tip
Minute teeth on lower leaf margins	Minute teeth on all leaves
Leaves not strongly curved backwards or twisted	Leaves are curved backwards (that is, recurved) or twisted

Both these species have small white-pink flowers that float at the water surface on very long, thin stalks. They have three petals and sepals.

Nuttall's waterweed *Elodea nuttallii* is becoming more frequent than Canadian waterweed *E. canadensis*, most likely due to eutrophication. Nuttall's waterweed is also more tolerant of poorer water quality, disturbance and management.

Key problems caused

- These species forms dense, single-species stands which out-compete native species for light and nutrients.
- Dense infestations can impede flows in some situations.
- Dense infestations can interfere with fishing and boating activities.

All waterweed *Elodea* spp. are non-native invasive species in the UK listed in Schedule 9 of the Wildlife and Countryside Act 1981 (as amended). It is an offence to plant or cause their spread in the wild.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques have a short-term impact, but waterweed species can regenerate from very small fragments so care must be taken and cut material must be carefully managed. Continued and regular cutting will weaken these plants and reduce the infestation.	March to September (regular treatment likely to be required)	7.3
Chemical	None available	n/a	n/a
Environmental	Waterweeds *Elodea* spp. can tolerate some shade, but water dyes have been found to be effective in static waters. Other methods which generate dense shade (for example, tree planting, sheets of opaque material) can be effective.	Spring and autumn n/a	7.5.3 7.5.1 7.5.2
Biological	Common carp *Cyprinus carpio*, and other bottom feeding fish, create turbid water which can help to reduce regrowth of these species.	n/a	7.6.3
Novel	None recommended	n/a	n/a

Another non-native waterweed species, South American waterweed *Elodea callitrichoides*, has also been recorded locally in southern England and Wales having first been recorded in 1948. In the light of changing climate and other possible garden escapes/ releases this species may become problematic in the future and require control. It is considered that appropriate methods for the control of other waterweed species would also be applicable to this species. This species is also listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended).


Canadian waterweed *Elodea canadensis* © JBA Consulting

5.2.8 Curly water-thyme *Lagarosiphon major*

Curly water-thyme *Lagarosiphon major*

Curly water-thyme *Lagarosiphon major* (sometimes also known as curly waterweed) is a non-native invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended). It is an offence to plant or cause its spread in the wild. It was first recorded in Britain in 1944 and has since spread widely.

It is a very aggressive species and can even out-complete waterweed *Elodea* species in alkaline waters.

The plant superficially resembles waterweed *Elodea* species with short, linear leaves between 1 and 3 mm in width and 6–30 mm in length. The leaves are strongly curved back on themselves (that is, recurved), so that the leaf tips point at the stem below. The leaves are either arranged in whorls or spirals of three around the stem, with those at the base of the plant always in spirals unlike waterweed *Elodea* species which have leaves which are always in whorls.

All British plants of curly Water-thyme *Lagarosiphon major* are thought to be female and spread of this plant is achieved vegetatively by the rooting of small fragments. Curly water-thyme *Lagarosiphon major* will grow in waters up to 3 m deep, although it will not tolerate fast-flowing conditions. It tends to occur in canals, drainage ditches and slow-flowing rivers and streams. Because of its ability to raise pH to over 10 (through the way its leaves take up carbon which results in calcium carbonate encrustation on the leaf surface), it can dominate plant communities, especially in still waters, as few other species can photosynthesise at this pH value.

Curly water-thyme *Lagarosiphon major*

Key problems caused

- This species can form single-species stands which out-compete native species. It can also alter water chemistry inhibiting the growth of native species and can, therefore, form dense infestations.
- Dense infestations can impede flows in some situations.
- Dense infestations can interfere with fishing and boating activities.

Technique type	Applicability	Timing	Relevant sections
Physical	Curly water-thyme *Lagarosiphon major* can be partly controlled by physical techniques, although only in the short-term and this is rarely the most effective technique. **Care must be taken to harvest all fragments** as plants can generate from these and start new colonies if they drift downstream.	Mid July-September	7.3 7.3.2
Chemical	None available	n/a	n/a
Environmental	Shade can help to reduce infestations and benthic barriers (that is, jute matting) have been trialled in some countries. Increasing flows may reduce the infestations of this species at one location, but this can result in fragments being washed downstream to establish new colonies elsewhere. Deepening waters to over 4 m may help to control this species, but this option is rarely practical.	n/a n/a n/a	7.5.1 7.5.2 7.5.5 7.5.4
Biological	None recommended	n/a	n/a
Novel	None recommended	n/a	n/a

Curly water-thyme *Lagarosiphon major*

© Laura Thomas

5.3 Floating-leaved plants – free-floating plants

Free-floating plants are not attached to the sediment and float on the water surface, moving unrestrictedly around according to winds and currents. Free-floating plants in the aquatic environment include duckweeds (for example, *Lemna* spp. and *Spirodela* spp.) and several non-native species, the most prevalent and problematic being water fern *Azolla filiculoides*.

Other free-floating non-native species include water hyacinth *Eichornia crassipes* and water lettuce *Pistia stratiotes*; at present these are only rarely recorded in the wild in the UK and often do not persist to require management. These species are therefore not given dedicated descriptions in this guide. In the future, as a result of climatic and environmental change, these species may become increasingly problematic.

Free-floating plants tend to be most abundant in slow-flowing and static waters. They are unlikely to cause major issues for flood risk management and land drainage as they do not impede flow and are washed downstream during high flows. They can be drawn into water intakes, block pumps and filters, and can mat together forming floating rafts which can sometimes cause flow problems and obstructions of weirs, locks and other structures.

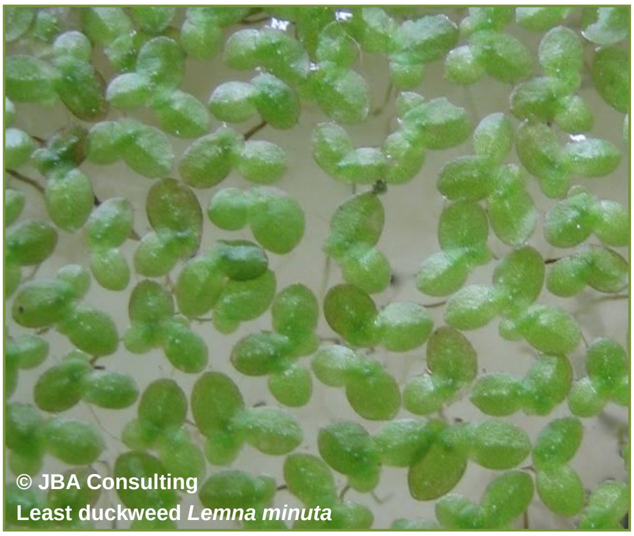
Frogbit *Hydrocharus morsus-ranae* is a native free-floating species with roots that tend to hang in the water. It is found in ponds, drainage ditches and canals. It is a relatively uncommon and declining species and should not be subject to management. Where it is harvested as part of other management operations it should be returned to the watercourse as soon as possible.

Frogbit *Hydocharus morsus-ranae*

Problematic free-floating species discussed below include:

- duckweeds (*Lemna* spp., *Spirodela* spp.)
- water fern *Azolla filiculoides*

5.3.1 Duckweeds (*Lemnaceae)*



© JBA Consulting
Least duckweed *Lemna minuta*

There are several duckweed species in Britain, including:

- common duckweed *Lemna minor*
- greater duckweed *Spirodela polyrhiza*
- fat duckweed *Lemna gibba*
- ivy-leaved duckweed *Lemna trisulca*
- rootless duckweed *Wolffia arrhiza*
- least duckweed *Lemna minuta*

All these species are native apart from least duckweed *Lemna minuta* which is naturalised from North America. Rootless duckweed *Wolffia arrhiza* is a very rare species and will not require management. **Care should be taken to ensure this duckweed species is not present prior to management**.

All species produce small, round or oval floating plants on the surface of the water, with the exception of ivy-leaved duckweed *Lemna trisulca* which typically floats within the water column and is rarely problematic. The table below summarises the key features and differences with the duckweed species found in the UK.

Common duckweed	Greater duckweed	Fat duckweed	Ivy-leaved duckweed	Rootless duckweed	Least duckweed
1–8 mm long	1.5–10 mm long	3–5 mm long	3–15 mm long (plus stalk)	0.5–1.5 mm long	0.8–4 mm long
Single long root	Several long roots	Single long root	No or only one root	No roots	Short roots
3–5 veins	Often red-purple below	Often white, spongy and swollen below (can be flat)	Complex branched structure. Translucent.	Ovoid in shape (can be rolled in your fingers)	1 vein

Duckweeds *Lemnaceae* are found in still and slow-flowing waters, and are often most prolific where conditions are nutrient-rich. The individual plants can occur singly (as in least duckweed *Lemna minuta* or fat duckweed *Lemna gibba*) or clumped together in groups of two or three (as in common duckweed *Lemna minor*).

Reproduction in duckweeds *Lemnaceae* is mainly vegetative,

© JBA Consulting
Common duckweed *Lemna minor*

with daughter buds forming new leaves which break off from the adult. Summer growth can be very rapid, and in dense infestations, duckweeds *Lemnaceae* can form a mat up to 20 cm thick.

Key problems caused

- Duckweeds *Lemnaceae* can block water intakes, pumps and filters.
- Large mats can block weirs, sluices and other structures leading to localised flood risk issues.
- These species block out light to submerged species causing them to die off.


Common duckweed *Lemna minor* © Shire Group of IDBs

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques can be effective when used in conjunction with booms which collect the plants in one area for removal. This is particularly effective in small watercourses. Mechanical harvesters/ suction harvesting is effective in larger watercourses. It is impossible to remove all plants through physical techniques and re-infestation is inevitable.	Mid July to September	7.3 7.3.2
Chemical	Glyphosate-based herbicides can be used on single layer and small infestations of duckweeds *Lemnaceae*, but they are not effective where thick mats have formed as only the top layers will be killed and regrowth will be rapid. Least Duckweed *Lemna minuta* is resistant to glyphosate-based herbicide treatment.	May to July n/a	7.4.1 n/a
Environmental	Manipulation of water flows using control structures can flush out infestations. Increased disturbance (for example, boat traffic) can reduce occurrence of these species. Shading, through a variety of methods, can successfully control duckweeds, although deep shade is often needed.	n/a n/a n/a	7.5.5 7.5.1 7.5.2
Biological	None recommended	n/a	n/a
Novel	None recommended	n/a	n/a

5.3.1 Water fern *Azolla filiculoides*

© Martin Redding, Witham Fourth District IDB
Water fern *Azolla filiculoides*

Water fern *Azolla filiculoides* is the only confirmed species of aquatic floating fern found in the UK, reproducing both from spores and vegetatively.

It has very small, oval, closely overlapping leaves along short branched stems and can superficially resemble duckweed *Lemnaceae* species.

A key characteristic of water fern is the red colouration that the plant takes on over winter, or when stressed (see photographs in this section). During the summer it is usually green in colour.

It can form dense mats which rapidly develop from vegetative growth or mass germination of spores. It is a species of static or slow-moving waters.

Key problems caused

- It can completely cover water surfaces causing a health and safety risk to children, pets and livestock as it resembles solid ground.
- Water fern *Azolla filiculoides* blocks out light to submerged species causing them to die off which can cause deoxygenation.
- It can block water intakes, pumps and filters.
- Large mats can block weirs, sluices and other structures.

Water fern *Azolla filiculoides* is a species native to North America and is currently considered a non-native invasive species in the UK. It is listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild. However, studies have found fossil remains of this species in Quaternary interglacial deposits in Suffolk, suggesting that this species was once present within the UK and could be considered native.


© Laura Thomas
Water fern *Azolla filiculoides*

Technique type	Applicability	Timing	Relevant sections
Physical	Conventional physical techniques have little impact on this species as it is difficult to remove all fronds. Reinfestation is inevitable particularly if spores have already been released. Vacuum suctioning and mechanical harvesters can have some benefit. The use of booms or baffle boards to collect plants in one area prior to removal by physical means is recommended.	n/a	7.3 7.7.4 7.3.2
Chemical	Glyphosate-based herbicides are effective, but only when growth does not exceed a single layer. Follow-up treatments are likely to be required. Glyphosate-based herbicides are not effective on thick mats.	April to July	7.4.1
Environmental	Limited opportunity for control by environmental methods. Shading methods or increasing disturbance through elevated boat traffic may have some impact on infestations.	n/a n/a	7.5.1 7.5.2
Biological	The North American weevil *Stenopelmus rufinasus,* which is now ordinarily resident in the UK, can be purchased to control infestations effectively. This can be used on both large and small infestations.	Spring (although can be released all year)	7.6.4
Novel	None recommended	n/a	n/a

Water fern *Azolla filiculoides*
© Shire Group of IDBs

Water fern *Azolla filiculoides*
© Murray Bush, Environment Agency

5.4 Floating-leaved plants – rooted floating-leaved plants

In contrast to free-floating species, this group of floating aquatic plants root in the bottom sediments of watercourses and have long stems or petioles which extend up through the water column to the surface where the leaf blades lie. They can often suppress the growth of other submerged aquatic plant species through shading.

This group of species does not often cause major issues for flood risk management and land drainage as they do not generally impede flow, unless growing at high densities. They can interfere with recreation and navigation, and management activities are usually focused on partial control, ensuring that central channels remain clear.

Problematic rooted floating-leaved species discussed below include:

- broad-leaved pondweed *Potamogeton natans*
- water-lilies *Nuphar* spp. and *Nymphaea* spp.
- fringed water-lily *Nymphoides peltata*
- arrowhead *Sagittaria sagittifolia*
- water-starworts *Callitriche* spp.
- floating pennywort *Hydrocotyle ranunculoides*
- water-primroses *Ludwigia* spp.

© JBA Consulting
Amphibious bistort *Persicaria amphibia*

A number of other rooted floating-leaved species occur in watercourses in the UK. These rarely require management and specific sections on these species are not included in this guide.

Amphibious bistort *Persicaria amphibia* may be found within an aquatic and riparian habitat, but is unlikely to require management as it rarely forms extensive stands. This species can occur either terrestrially, or within water in an aquatic form. It has oblong leaves with heart-shaped bases and pointed tips. It has pink flowers which emerge above the water surface.

Other rooted floating-leaved species that may be encountered include a number of sweet-grasses, predominantly floating sweet-grass *Glyceria fluitans,* but also potentially small sweet-grass *G. declinata* or plicate sweet-grass *G. notata,* and some bur-reeds, principally unbranched bur-reed *Sparganium emersum,* but also possibly least bur-reed *S. natans* or floating bur-reed *S. angustifolium*. These latter species have long, linear leaves that either float on the water surface or are submerged below it, in the direction of flow. They also have emergent flowering stems and some emergent leaves.

5.4.1 Broad-leaved pondweed *Potamogeton natans*


Broad-leaved pondweed *Potamogeton natans* © JBA Consulting

Broad-leaved pondweed *Potamogeton natans* is a species of slow-flowing and static waters. It can grow in water up to 1.5 m in depth from rhizomes rooted in the sediments at the bottom of watercourses.

This species has elliptical leaves that float on the water surface and flowers that emerge above, producing viable seed – although the plant principally spreads vegetatively from rhizomes. To allow the leaves to float on the water surface this species has a flexible joint where the leaf stalk meets the leaf blade; as water levels change, this joint moves so that leaves remain floating on the water surface.

Key problems caused

- The leaves of broad-leaved pondweed *Potamogeton natans* can form a dense cover over the water surface impeding fishing and other recreational activities.
- In some circumstances flows can be impeded causing flood risk management and land drainage issues.

As a positive for plant management, the dense canopy of the leaves of this species shade the water column below and can help to suppress the growth of other aquatic plants, especially algae and submerged species such as waterweeds *Elodea* spp. (see section 5.2.7).

The true pondweeds *Potamogeton* spp. are a group of 21 native species, plus a number of hybrids. A large number of these pondweeds *Potamogeton* spp. have an entirely submerged growth habit (see section 5.2.3), whereas others have floating leaves. While broad-leaved pondweed *Potamogeton natans* is the floating-leaved pondweed species that causes the most problems, others can be quite scarce (for example, fen pondweed *P. coloratus* and loddon pondweed *P. nodosus*). **Care should be taken to accurately identify the species prior to management** (see section 5.1).


Broad-leaved Pondweed *Potamogeton natans* © Shire Group of IDBs

Technique type	Applicability	Timing	Relevant sections
Physical	Most physical techniques are effective on this plant, although manual methods are less so, and generally control is only in the short-term for one season only. Cutting is recommended later in the season to limit regrowth. De-weeding with a solid bucket has a longer term impact as rhizomes are removed.	Mid July to September	7.3 7.3.4
Chemical	Glyphosate-based herbicides do not give satisfactory control, although if used with an adjuvant effectiveness is increased.	July to August	7.4.1
Environmental	Shading, through a variety of methods, is effective. Deepening the channel to more than 2 m may limit growth and the areas that this species can colonise, but may not be practical.	n/a n/a	7.5.1 7.5.2 7.5.4
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a


© JBA Consulting
Broad-leaved pondweed *Potamogeton natans*

5.4.2 Water-lilies *Nuphar* spp. and *Nymphaea* spp.

Water-lilies are plants of static and slow-flowing water bodies. They are characterised by their floating oval/circular leaves and yellow or white flowers. They can grow in water depths of up to 5 m but favour 1–3 m.

Yellow water-lily *Nuphar lutea*

There are three native water-lily species in the UK; the most common in watercourses is yellow water-lily *Nuphar lutea* (see photograph opposite). White water-lily *Nymphaea alba* (see photograph below) occasionally occurs in watercourses and management of this species should be carefully considered. A third species, least Water-lily *Nuphar pumila*, is quite uncommon. **Care should be taken to accurately identify the species prior to management**. The table below summarises the key features to identify these three species.

Yellow water-lily *Nuphar lutea*	**White water-lily *Nymphaea alba***	**Least water-lily *Nuphar pumila***
Leathery heart-shaped floating leaves	Almost circular floating leaves	Leathery heart-shaped floating leaves
Has submerged, thin 'cabbage' leaves on triangular stems	Mature leaves rarely submerged, and if so like floating leaves	
Leaves up to 40 × 30 cm	Leaves 9–30 cm diameter	Leaves up to 17 × 12.5 cm
23 or more veins divided in parallel, 'tuning forks'	Leaf veins join up to form a network	18-11 veins divided in parallel, 'tuning forks'
Large yellow flowers	Large white flowers	Small yellow flowers

White water-lily *Nymphaea alba*

Water-lilies form extensive slow-spreading rhizomes from which leaves and flowers arise each year. The narrow leaf and flower stalks cause little flow impedance. Also, the shading effect of the leaves can help to control submerged plants and algae.

Key problems caused

- Dense cover of leaves may impair recreational activities.
- Dense cover of leaves may cause deoxygenation as a result of die-back of submerged species from the shading generated.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques using a variety of methods provide short-term control, but rapid regrowth of leaves typically occurs later in the season or the following spring. De-weeding with a solid bucket removes rhizomes and provides longer term control of more than one season; this is rarely entirely effective.	Mid July to September	7.3 7.3.4
Chemical	Glyphosate-based herbicide application to the floating leaves is effective. No chemical control technique is available for the submerged 'cabbage' leaves of yellow water-lily.	July to August	7.4.1
Environmental	Shading, through a variety of techniques, is effective. Deepening the channel to more than 2 m may limit growth and the areas that this species can colonise, but may not be practical.	n/a n/a	7.5.1 7.5.2 7.5.4
Biological	Ducks readily eat the buds and submerged leaves of water-lilies; increasing waterfowl populations may have some impact, but there is limited ability to control this technique and associated impacts of nutrient enrichment may arise.	n/a	7.4.1
Novel	None recommended	n/a	n/a

5.4.3 Fringed water-lily *Nymphoides peltata*

© JBA Consulting
Fringed water-lily *Nymphoides peltata*

Fringed water-lily *Nypmhoides peltata* is not in the same family as other water-lily species found in the UK, but grows in a similar form. Its leaves and flowers are smaller than other water-lily species and it generally prefers shallower waters (up to 1.5 m deep).

Fringed water-lily *Nypmhoides peltata* has round to kidney-shaped leaves, which are purple below, 3–10 cm across and have an undulating margin. It has yellow flowers which have five petals and fringed yellow lobes, which give the species its name.

This species occasionally grows in flowing waters but is more typical of ponds and small lakes. It is uncertain as to whether this is a native species. It was once considered quite rare and was subject to conservation measures, but it is becoming increasingly common and widespread and has started to create problems.

Key problems caused

- Dense cover of leaves may impair recreational activities, including boating, angling and swimming.
- Dense cover of leaves may cause deoxygenation as a result of die-back of submerged species from the shading generated.

© JBA Consulting Fringed water-lily *Nymphoides peltata*

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques using a variety of methods provide short-term control, but rapid regrowth of leaves typically occurs later in the season or the following spring. De-weeding with a solid bucket removes rhizomes and provides longer term control of more than one season; this is rarely entirely effective.	Mid July to September	7.3 7.3.4
Chemical	Glyphosate-based herbicides are not very effective on this species and control is unreliable. The use of adjuvants with glyphosate-based herbicides has increased their effectiveness.	July to August	7.4.1
Environmental	Shading, through a variety of techniques, can be effective. Deepening the channel to more than 1.5 m may limit growth and the areas that this species can colonise, but may not be practical. Flow characteristics (for example, increasing flow rates) may discourage this species which generally prefers slow-flowing and static waters.	n/a n/a n/a	7.5.1 7.5.2 7.5.4 7.5.5
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

5.4.4 Water-starworts *Callitriche* spp.


Water-starwort *Callitriche spp.*
© Sarah Warriss-Simmons

Water-starworts *Callitriche* spp. are a group of species that inhabit watercourses, pools and damp mud.

They are slender, delicate plants, with opposite pairs of linear or oval leaves. Many species also have upper leaves very close together so that they form a floating terminal rosette. The leaf tips are also usually notched. They are perennial species and easily reproduce by seed and vegetative methods.

They are a very difficult group of species to identify. Identification can often only be reliably made by examination of the fruit shape and structure. Where fruits are not present, the species cannot often be successfully identified. They are also a very variable group of species, taking on different leaf shapes in different environmental conditions.

This group of species does not often cause problems and several of the species in this group are quite scarce; care is necessary when deciding whether or not to manage a water-starwort species. They are also an important source of food for a number of aquatic species, including fish and aquatic macroinvertebrates, and provide habitat and cover.

Key problems caused

- Dense growth in narrow watercourses can impede flows.
- They can form dense single-species stands.


Water-starwort *Callitriche* spp.
© Sarah Warriss-Simmons

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, using a variety of methods, can control these species in the short term, although fragments of this plant can be viable and regrow and spread downstream.	Mid July to September	7.3
Chemical	None available (significant proportions of the plant are submerged).	n/a	n/a
Environmental	Deepening the channel to more than 1 m may limit the areas that this species can colonise, but this may not be practical in many situations. Shading, through a variety of techniques, may be effective although deep shade is likely to be required.	n/a n/a	7.5.4 7.5.1 7.5.2
Biological	Wildfowl will eat the submerged plant material; increasing waterfowl populations may have some impact, but there is limited ability to control this technique and associated impacts of nutrient enrichment may arise.	n/a	7.6.2
Novel	None recommended	n/a	n/a

5.4.5 Arrowhead *Sagittaria sagittifolia*

© JBA Consulting
Arrowhead *Sagittaria sagittifolia*

Arrowhead *Sagittaria sagittifolia* is an aquatic species with distinctive arrow-shaped floating and emergent leaves, although leaf shape can be very variable with the floating leaves often elliptical in shape. It also has distinctly different submerged leaves which are long, linear and translucent in nature.

This species has white flowers, 2–3 cm across, with a purple base. They are held on a stalk in whorls of 3–5, which emerge above the water surface.

The species over-winters as detached submerged buds.

Arrowhead *Sagittaria sagittifolia* is a species of canals, drains, slow-flowing watercourses and also ponds. It is generally found where conditions are eutrophic to mesotrophic, but it is intolerant of anything more than a low level of pollution.

Key problems caused

- It can form dense stands and in narrow watercourses this can impede flows and reduce channel capacity.
- It can interfere with fishing and boating activities.

© JBA Consulting
Arrowhead *Sagittaria sagittifolia*

In the UK there are also a few non-native species within the *Sagittaria* family that occur in watercourses, including:

- duck-potato *Sagittaria latifolia*
- Canadian arrowhead *S. rigida*
- narrow-leaved arrowhead *S. subulata*

All are very localised in their distribution. While these are non-native species, they are not currently causing significant issues in the wild in the UK. In the face of climatic and environmental change they may become increasingly problematic in the future.

Duck-potato *Sagittaria latifolia* is listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, using a variety of methods, can control these species in the short term, although viable fragments often remain and regrow.	Mid July to September	7.3
Chemical	Glyphosate-based herbicides are effective on the emergent growth of this species.	July to August	7.4.1
Environmental	Shading, through a variety of techniques, may be effective although deep shade is likely to be required. Deepening the channel to more than 1 m may limit the areas that this species can colonise, but this may not be practical in many situations.	n/a n/a	7.5.1 7.5.2 7.5.4
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

5.4.6 Floating pennywort *Hydrocotyle ranunculoides*

Floating pennywort *Hydrocotyle ranunculoides*

Floating pennywort *Hydrocotyle ranunculoides* is a species native of North America which was first introduced to Britain in the 1980s by the horticultural trade. It is now widespread and well-established in the south and east of England, and appears to be spreading rapidly north and westwards.

It has circular or kidney-shaped leaves which are divided around half way to the base and they are also lobed.

It is a species of slow-moving canals, rivers and ditches and can be very fast growing. It can grow at up to 20 cm per day. It can also form dense interwoven mats extending a significant distance above and beneath the water surface.


Floating pennywort *Hydrocotyle ranunculoides*
© Phil Harding, Environment Agency

This species roots readily at the nodes and reproduction is principally by vegetative means.

Floating pennywort *Hydrocotyle ranunculoides* is a non-native invasive species in the UK. It is listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild.

Key problems caused

- It can form dense, interwoven mats of vegetation which can rapidly cover the water surface, impeding flows and blocking weirs and other structures.
- It can adversely impact on the native ecology of watercourses by forming dense, interwoven single-species stands which out-compete native emergent species and block out light to submerged species.
- It can impair amenity uses of the watercourse, including boating and fishing.

Floating pennywort *Hydrocotyle ranunculoides* is one of the most problematic non-native invasive species in the UK. It is estimated to be currently the most expensive of all aquatic plants to control, with approximately £1.93 million spent in the UK on managing this species annually (Williams et al*.* 2010).

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, by a variety of methods, can control floating pennywort in the short term. However, this is not advised unless there are measures put in place to stop the spread of cut material downstream (for example, booms). Hand pulling is often effective to remove small infestations, or following control by other techniques.	March to October	7.3 7.3.1
Chemical	Glyphosate-based herbicides alone are often not very effective as this plant actively transports the chemical out of its roots. Furthermore it has a waxy leaf covering which is hard to penetrate, and as it forms thick mats it is difficult to apply the chemical to all parts. Following treatment recovery is often rapid. The use of adjuvants increases the effectiveness of glyphosate-based herbicides significantly. Follow-up treatments are always likely to be necessary.	March to October (with treatment starting early in the growing season)	7.4.1
Environmental	Shade, by a variety of techniques, can be effective. This species cannot tolerate fast flows, so manipulating flow characteristics to increase flow rates may restrict growth in some channels. Deepening the channel to more than 1 m may limit the areas that this species can colonise may limit growth, but may not be practical.	n/a n/a n/a	7.5.1 7.5.2 7.5.5 7.5.4
Biological	Cattle grazing has been reported to damage the emergent stems, but the long-term effects are unknown.	n/a	7.6.1
Novel	None recommended	n/a	n/a
Integrated	Physical techniques are recommended to reduce the extent of the infestation before herbicide is applied.	March to October	7.8

There are also other non-native pennywort *Hydrocotyle* species in the UK, including hairy pennywort *Hydrocotyle moschata* and New Zealand pennywort *H. novae-zeelandiae.* Although these are non-native species, they are not currently causing significant issues in the wild in the UK. In the face of climatic and environmental change they may become increasingly problematic in the future. Other ornamental pennywort species, such as *H. sibthorpioides* and *H. verticillata* could also potentially be problematic should they establish in the wild.

Example: Floating pennywort on the rivers Soar and Mole

The River Mole in Surrey and the River Soar in Leicestershire are two watercourses that have both suffered extensively from infestations of floating pennywort *Hydrocotyle ranunculoides*. As a result, large-scale management programmes have been implemented by the Environment Agency.


River Mole
© Michele Cooper, Environment Agency

The River Mole, in its downstream reaches around East Moseley, has suffered from dense infestations of floating pennywort for the past 13 years, with extensive floating rafts developing within the channel in many years. These large rafts create localised flood risk management issues when they block weirs and sluices. In 2012, £38,000 was spent in trying to control floating pennywort on this stretch of river alone.

Floating pennywort was first recorded on the River Soar in Leicester in 2004. By 2006 it had formed extensive beds through the city and was extending downstream into Leicestershire and towards the River Trent, causing severe problems for river uses including navigation, recreation and fisheries.

Many different approaches to managing this species have been attempted. On the River Mole management has been undertaken primarily using physical techniques, with occasional herbicide use. The mechanical use of weed boats and de-weeding with a weed bucket has been tried, but was considered to create too many fragments, increasing the risk of spread. Consequently management by hand, either from a boat or from within the channel, has been the main method. On the River Soar, since 2006, a variety of management approaches have been applied working in partnership with the Canal & River Trust and Leicester City Council. Initially this involved mechanical and manual removal, similar to the River Mole, which proved successful but expensive. Therefore, since 2010, glyphosate-based herbicide with adjuvant use has been the preferred method of control, supplemented with hand pulling by volunteers.

Herbicide treatment has been found to be very effective on the River Soar, providing cost-effective management even where the plant is extensively established. It was found to be a flexible technique, allowing treatment of the entire length affected and also re-treatment throughout the year where necessary; this kept the infestations small and more manageable. By 2013, the predominant use of physical techniques on the River Mole has also had significant successes, with only occasional patches now reported. The local Environment Agency team has adopted a rapid intervention approach so that any small infestations identified are treated immediately, preventing them becoming extensive and requiring more large-scale and costly management.


River Soar 2009 - No management
© Phil Harding, Environment Agency


River Soar 2010 - Post herbicide treatment
© Phil Harding, Environment Agency

5.4.7 Water-primroses *Ludwigia* spp.


Water-primrose *Ludwigia grandiflora* © JBA Consulting

Water-primroses *Ludwigia spp*. are from South America and have been introduced to the UK relatively recently from the horticultural trade. They are taxonomically a difficult group to separate out into different species. In the UK *Ludwigia grandiflora* and *L. peploides* have been recorded, although identification to species level is difficult. These two water-primroses *Ludwigia* spp. are non-native, invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended), along with *Ludwigia uruguayensis* which has not yet been recorded in the UK, and it is an offence to plant or cause their spread in the wild. Although these species has not yet caused serious problems in the UK, elsewhere in Europe this species has been extremely problematic and any infestations of this species must be controlled as soon as possible.

Water-primroses *Ludwigia* spp. grow not only in water but also in marginal habitats and can look quite different when growing in these different habitats. They have leaves which are variable in shape (see photographs below), ranging from long and slender to oval and spoon-shaped. The leaves are green in colour, with distinctly paler veining.


Water-primrose *Ludwigia grandiflora* © JBA Consulting

Water-primroses *Ludwigia* spp. have flowers which are bright yellow, five-petalled and approximately 3 cm across. The plants flower between July and September, and during the winter they die back leaving brown stems.

They can spread by seeds, but the primary mechanism of spread is believed to be from fragmentation of plant material.

Key problems caused

- It can form dense infestations which can rapidly cover the water surface, impeding flows.
- It can adversely impact on the native ecology of watercourses by forming single-species stands which out-compete native species and block out light to submerged species.
- It can impair amenity uses of the watercourse, including boating and fishing.

Water-primrose *Ludwigia grandiflora*

Water-primrose *Ludwigia grandiflora*

There is also one native *Ludwigia* species in the UK: Hampshire-purslane *Ludwigia palustris*. This species is very rare and a species found in pools in the New Forest and is therefore highly unlikely to be encountered as part of watercourse management.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques, using a variety of methods, can be an effective method of control and it can be used to reduce biomass, particularly if stands are well established. Care should be taken when using physical techniques as this plant can spread from fragmentation. Measures should be put in place to prevent the downstream spread of material. Removed material must be composted away from water bodies.	May to October	7.3
Chemical	Glyphosate-based herbicides are effective on these species, particularly when used with an adjuvant. At least two years' treatment with herbicide is likely to be required to eradicate this species.	May to October	7.4.1
Environmental	Shading, through a variety of techniques, may have some impact in helping to limit the growth of this species.	n/a	7.5.1 7.5.2
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

5.5 Emergent species – tall emergent species

Emergent species are those which are rooted in sediments at the bottom of watercourses and grow in water usually no more than 1 m deep. The majority of leaves and stems extend above the water surface. Within this sub-group of emergent species, are generally very tall species (up to 3 m in height) with very long, narrow leaves.

Tall emergent species can be very problematic, particularly in narrow and relatively shallow watercourses, where they can completely block channels. In larger, deeper watercourses they tend to form margins along the bottom of the banks, where conditions are shallower and, in these instances, are not as problematic.

Potentially problematic tall emergent species discussed below include:

- common reed *Phragmites australis*
- reedmaces *Typha* spp.
- reed sweet-grass *Glyceria maxima*
- reed canary-grass *Phalaris arundinacea*
- common club-rush *Schoenoplectus lacustris*
- branched bur-reed *Sparganium erectum*

There are other tall emergent species that occur in watercourses in the UK. However, these rarely require management and specific sections on these species are not included in this guide. Such species include:

- yellow iris *Iris pseudacorus*
- rush species *Juncus* spp.

Yellow Iris *Iris pseudacorus* **© JBA Consulting**

5.5.1 Common reed *Phragmites australis*


© JBA Consulting
Common reed *Phragmites australis*

Common reed *Phragmites australis* is the tallest native grass species in the UK, and can grow up to 3 m in height. It has greyish-green leaves with a ligule composed of a ring of white hairs. Its flowers are dark purplish-brown in colour and are very highly branched.

This perennial species spreads through creeping rhizomes, which can grow up to 1 m below ground level. Common reed can cover large areas of swamp and fen, as well as forming dense stands within watercourses within the riparian zone. It can grow in both static and flowing waters. It is found throughout the UK, but is most common in lowland areas where it is a frequent species in the shallower waters of rivers and lakes, growing in water depths of up to one metre. It can also grow on areas of drier land which are only seasonally inundated.

The dense network of rhizomes that common reed *Phragmites australis* forms can be very useful on watercourses helping to stabilise banks and prevent erosion; management should aim to keep a fringe of this species along the toe of the banks to help protect and stabilise them.


Common reed *Phragmites australis*
© Sarah Warriss-Simmons

Common reed *Phragmites australis* is also an important plant, supporting a number of species, for example, by providing nesting habitat for birds such as reed bunting *Emberiza schoeniclus* and reed warbler *Acrocephalus scirpaceus*.

The shade they produce can also suppress the growth of other potentially problematic floating and submerged species (see section 7.5.1).

Fringes of riparian vegetation such as common reed *Phragmites australis* are also important in helping to attenuate overland run-off of soils and nutrient-rich waters, which may help to improve water quality of some watercourses in the long-term (see section 7.5.6).

Key problems caused

- Dense networks of rhizomes can form large stands which impede flows.
- Once established, the roots and rhizomes trap silt and extend the area that they can colonise, which further impedes water flow in the long-term.
- Dense stands can also impair fishing and other recreational activities.
- Following die-back during the winter months, the robust stems can remain standing and continue to cause problems.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control; however, many physical techniques do not remove the rhizomes and repeat management is necessary. The dead stems, which remain standing in winter, may also require cutting to prevent flows being impeded. De-weeding with a solid bucket is unlikely to extend to at a sufficient depth to allow for effective longer term control.	Mid July to December October to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes.	July to September	7.4.1
Environmental	Manipulating water levels to more than 1 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 1 m should also help in preventing encroachment across a watercourse, allowing just a fringe to develop along the bank toe; this has a number of benefits.	n/a n/a	7.5.4
Biological	Grazing and trampling by cattle, horses and sheep will help to control this species in riparian zones.	n/a	7.6.1
Novel	None recommended	n/a	n/a

5.5.2 Reedmaces *Typha* spp.


Common reedmace *Typha latifolia* © JBA Consulting

Reedmaces *Typha* spp., also known as bulrushes, are tall, robust plants that grow in water and wetland habitats. In the UK there are two species of reedmace:

- common reedmace *Typha latifolia* (see opposite)
- lesser reedmace *Typha angustifolia* (see below)

Both species have long, flat leaves that arise alternately from opposite sides of the stem. Both have a cylindrical spike of densely packed, very small flowers, the lower part of which is dark brown in colour and contains female flowers, and the upper part of which is narrower, yellow-brown in colour and contains the male flowers. Both species have rhizomes and they readily produce seed which allows rapid recolonisation of areas following disturbance or management. They can also tolerate relatively deep water levels of up to 1 m for common reedmace *Typha latifolia* and 1.5 m for lesser reedmace *Typha angustifolia*. The table below summarises the key differences.

Common reedmace *Typha latifolia*	**Lesser reedmace *Typha angustifolia***
1.5–2.5 m tall (possibly up to 3 m)	1.5–2.5 m tall
Leaves 8–24 mm wide	Leaves 3–6 mm wide and slightly curved on the back
Leaves grey-green in colour	Leaves bright in colour
No gap (or occasionally a gap of less than 2.5 cm) between the dark brown female part of the inflorescence and the yellow-brown male part	A gap of 3–8 cm between the dark brown female part of the inflorescence and the yellow-brown male part of the inflorescence
Female part of flower 3–4 cm wide	Female part of the flower 1.5–2.5 cm wide
A large robust plant	A more slender plant, but equally as tall

Lesser reedmace *Typha angustifolia* tends to be encountered less frequently than common reedmace *Typha latifolia*, but both species are found in still or slow-moving watercourses and swamp habitats, although lesser Reedmace *Typha angustifolia* tends to be present on more peaty soils. The dense network of rhizomes that these species forms can be very useful on


© JBA Consulting
Lesser reedmace *Typha angustifolia*

watercourses for bank stability and preventing erosion; management should aim to keep a fringe of this species along the toe of the banks.

The shade they produce can also suppress the growth of other potentially problematic floating and submerged species (see section 7.5.1). Fringes of riparian vegetation such as reedmaces *Typha* spp. are also important in helping to attenuate overland run-off of soils, which may improve water quality in the long term.

Key problems caused

- Dense networks of rhizomes can form large stands which impede flows.
- Once established, the roots and rhizomes trap silt and extend the area that they can colonise, which further impedes water flow in the long term.
- Dense stands can also impair fishing and other recreational activities.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control; however, many physical techniques do not remove the rhizomes and repeat management is likely to be necessary. Cutting is not recommended for mature stands of common reedmace as the thick stems can jam the cutting blades of weed buckets, boats and other machines with reciprocating cutters. De-weeding with a solid bucket may help to achieve longer term control through rhizome removal, if undertaken at sufficient depth.	Mid July to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes. Repeat treatments are likely to be required.	August to September	7.4.1
Environmental	Manipulating water levels to more than 2 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 1–1.5 m should also help in preventing encroachment across the watercourse allowing just a fringe to develop along the bank toe.	n/a n/a	7.5.4
Biological	Grazing and trampling by cattle, horses and sheep will help to control this species in riparian zones.		7.6.1
Novel	None recommended	n/a	n/a

5.5.3 Reed sweet-grass *Glyceria maxima*


Reed sweet-grass *Glyceria maxima*
© Sarah Warriss-Simmons

Reed sweet-grass *Glyceria maxima* is a wetland grass species, abundant in lowland areas. It inhabits the riparian zone of slow-flowing watercourses and canals, as well as ponds, lakes and marshes. It can grow in water depths of up to 1 m.

It can grow up to heights of 2.5 m, though it is usually somewhat shorter than this. It is usually bright green in colour, hairless and smooth, with leaves that have a keeled, pointed tip. It has a membranous ligule, unlike common reed *Phragmites australis* which has a ring of hairs, and this membrane has a distinct central point. The flowers of this species have several branches which are open and light brown in colour. This species spreads by far-creeping rhizomes which can cover large areas, and it can occasionally form floating rafts of vegetation.

There are several sweet-grass *Glyceria* species in the UK (see section 5.4). Reed sweet-grass *Glyceria maxima* is the largest species of this family, and is significantly taller and more robust, being much more upright in growth habit than the other species.

The dense network of rhizomes that this species forms can be very useful on watercourses by stabilising banks and preventing erosion; management should aim to keep a fringe of this species along the toe of watercourse banks to protect them. The shade produced by reed sweet-grass *Glyceria maxima* can also suppress the growth of potentially problematic floating and submerged species (see section 7.5.1). Fringes of riparian vegetation such as reed sweet-grass *Glyceria maxima* are also important in helping to attenuate overland run-off of soils and nutrient-rich waters, which may help to improve water quality of some watercourses. This species is also a notable food plant for grazing animals.


Reed sweet-grass *Glyceria maxima*

Key problems caused

- Dense networks of rhizomes can form large stands and impede flows.
- Once established, roots and rhizomes trap silt and extend the area that they can colonise, which further impedes water flow in the long term.
- Dense stands can also impair fishing and other recreational activities.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control; however, many physical techniques do not remove the rhizomes and repeat management is often necessary. De-weeding with a solid bucket may help to achieve longer term control through rhizome removal, if undertaken at sufficient depth.	Mid July to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and kills the plant by being translocated to the rhizomes. Reed Sweet-grass *Glyceria maxima* is a rapidly growing species and more frequent treatment compared with other tall emergent species, may be required. Early season treatment can help to reduce the risk of summer flooding.	August to September May to June	7.4.1
Environmental	Manipulating water levels to more than 1 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 1 m should also help in preventing encroachment across the watercourse allowing just a fringe to develop along the bank toe; this has a number of benefits.	n/a n/a	7.5.4
Biological	Grazing by cattle and sheep can be effective, particularly in and around shallow, hard-bottomed watercourses where livestock have access.	n/a	7.6.1
Novel	None recommended	n/a	n/a

5.5.4 Reed canary-grass *Phalaris arundinacea*

© Sarah Warriss-Simmons
Reed canary-grass *Phalaris arundinacea*

Reed canary-grass *Phalaris arundinacea* is a tall, wetland grass species that can grow up to 2 m in height, though it is usually smaller than this. It has hairless, green or grey-green leaves and while superficially similar to common reed *Phragmites australis* when not in flower, this species has a membranous ligule as opposed to the ring of hairs of common reed.

Its flower head usually has several branches with relatively dense clumps of flowers on each. These are often densely packed together, becoming more open through the season. This is a perennial species which has extensive creeping rhizomes.

It is a widely distributed species throughout the UK, often occurring along the margins of rivers, streams and drains, as well as in lakes, ponds and marshes. It generally grows in shallower waters than other tall emergent species (up to 30 cm) and it can also occur in more terrestrial habitats and on waste ground.

The dense network of rhizomes that this species forms can be very useful on watercourses for bank stability and preventing erosion; management should aim to keep a fringe of this species along the toe of the banks.

Reed canary-grass *Phalaris arundinacea*

This species, being intolerant of deeper waters, also tends not to be as problematic as other tall emergent species on larger watercourses and is generally confined to marginal areas where it acts as a useful bank stabilising plant.

Fringes of riparian vegetation such as reed canary-grass *Phalaris arundinacea* are also important in helping to attenuate overland run-off from soils and nutrient-rich waters, which may help to improve water quality of some watercourses over the long term. This species is also a useful grazing or hay grass species.

Key problems caused

- Dense networks of rhizomes can form large stands which impede flows in smaller watercourses.
- Once established, roots and rhizomes trap silt and extend the area that they can colonise, which further impedes water flow in the long term.
- Dense stands can also impair fishing and other recreational activities.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control; however, many physical techniques do not remove the rhizomes and repeat management is necessary and several cuts may be needed. De-weeding with a solid bucket may help to achieve longer term control through rhizome removal, if undertaken at sufficient depth.	Mid July to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes.	August to September	7.4.1
Environmental	Manipulating water levels to more than 0.5 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 0.5 m should also help in preventing encroachment across the watercourse allowing just a fringe to develop along the bank toe; this has a number of benefits.	n/a n/a	7.5.4
Biological	Grazing by cattle and sheep can be effective, particularly in and around shallow, hard-bottomed watercourses where livestock have access.	n/a	7.6.1
Novel	None recommended	n/a	n/a


Reed canary-grass *Phalaris arundinacea*
© Laura Thomas

5.5.5 Common club-rush *Schoenoplectus lacustris*


© JBA Consulting
Common club-rush *Schoenoplectus lacustris*

Common club-rush *Schoenoplectus lacustris* is a tall emergent species from the sedge *Cyperaceae* family. It can grow up to 3 m (sometimes 3.5 m) in height and has spongy cylindrical stems, over 1 cm wide at the mid-point. It is dark green in colour, sometimes with a dark blue-green hue. Its flowers form at the top of the stem and are chestnut-brown and grouped in clusters.

Although typically growing in emergent form, as illustrated, it can also form long (up to 1 m), linear submerged leaves, usually when growing in faster flowing waters.

It is a species of relatively shallow waters, but can tolerate water depths of up to 1.5 m, although it generally grows in depths less than this. It prefers slow-flowing and static waters of rivers, canals and ditches, along with lakes and ponds.

It has extensive creeping rhizomes and can often form single-species stands.


Common club-rush *Schoenoplectus lacustris*
© Sarah Warriss-Simmons

Key problems caused:

- Can form large stands which impede flows.
- Rhizomes trap silt which extends the area that this species can colonise, further impeding flow. It can deflect flows onto banks and cause erosion.
- Dense stands can also impair fishing and other recreational activities.

The dense network of rhizomes that common club-rush *Schoenoplectus lacustris* forms can be very useful on watercourses for bank stability and preventing erosion; management should aim to keep a fringe of this species along the toe of the banks to help protect and stabilise them. This species also provides good cover for wildfowl species.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques can be used on this species, but many, such as cutting, offer only short-term, single season control. Physical techniques result in large volumes of harvested material which require disposal. De-weeding with a solid bucket provides longer-term control as rhizomes are removed. It may be difficult to remove all the rhizomes and regrowth is likely to be rapid.	Mid July to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes. Glyphosate-based herbicides are not effective on the submerged linear leaves.	August to September	7.4.1
Environmental	Manipulating water levels to more than 1.5 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 1.5 m should also help in preventing encroachment across a watercourse allowing just a fringe to develop along the bank toe; this has a number of benefits.	n/a n/a	7.5.4
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

© JBA Consulting
Common club-rush *Schoenoplectus lacustris*

5.5.6 Branched bur-reed *Sparganium erectum*

Branched bur-reed *Sparganium erectum*
© Shire Group of IDBs

Branched bur-reed *Sparganium erectum* is a native plant which grows in the silty mud at the margins of slow-flowing rivers, streams, canals and drainage ditches in water usually 10–50 cm deep. It is a relatively shallow-rooted species and cannot usually persist in faster flowing waters. It cannot withstand prolonged inundation at depths above its preferred water level range. It also prefers nutrient rich waters.

It is a widespread, perennial species with extensive creeping rhizomes. It has leaves which have a distinctive triangular shape in cross section, formed as a result of a strong keel down the back of the leaf blade. Its flowers, which form on branched stems, are globular, spiky-looking spheres, with the male and female different in form. It is usually bright green in colour and can grow to a height of 1.5 m.

Branched bur-reed *Sparganium erectum*
© Sarah Warriss-Simmons

In the UK there are four bur-reed *Sparganium* species. Branched bur-reed *Sparganium erectum* is the largest and the only one that has flower heads on a branched stem. It is also generally an erect species, whereas the others all have submerged linear leaves and are typically much smaller.

The other species, unbranched bur-reed *S. emersum*, least bur-reed *S. natans* and floating bur-reed *S. angustifolium* are generally not problematic in the aquatic and riparian environment and therefore do not require management to the same extent as branched bur-reed *S. erectum*. In the case of least bur-reed *S. natans* and floating bur-reed *S. angustifolium*, these species are relatively scarce and should be retained.

Key problems caused

- Can form large stands which impede flows and reduce channel capacity, particularly in shallow silty watercourses.
- Rhizomes trap silt which extends the area that this species can colonise, further impeding flows.
- Dense stands can also impair fishing and other recreational activities.

The dense network of rhizomes that branched bur-reed *Sparganium erectum* forms can be very useful on watercourses for bank stability and preventing erosion; management should aim to keep a fringe of this species along the toe of the banks to help protect and stabilise them. Bur-reed fruits are also a source of food for wildfowl.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control; however, most physical techniques do not remove the rhizomes and regrowth following cutting is often rapid. Regular cutting can reduce the vigour of stands and can eliminate this plant. The leaves and roots are bulky and physical techniques can result in waste disposal issues. De-weeding with a solid bucket to remove rhizomes is likely to result in longer-term control. In localised areas, as the plant is shallow-rooted and grows in shallower waters, hand pulling or cutting can be undertaken.	Mid July to December	7.3 7.3.4 7.3.1
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes.	July to September (before frosts)	7.4.1
Environmental	Shading, through a variety of methods, can be an effective control. Manipulating water levels by lowering for 6–12 weeks to dry stands out can control this species. Manipulating water levels to more than 0.5 m for a prolonged period of time may help to control stands by making conditions unsuitable. Creating a deeper central channel of more than 0.5 m should also help in preventing encroachment across the watercourse allowing just a fringe to develop along the bank toe; this has a number of benefits. Manipulating flow rates to significantly increase them may also help reduce stand extents by uprooting shallow-rooted plants.	n/a n/a n/a n/a n/a	7.5.1 7.5.2 7.5.4 7.5.5
Biological	Cattle and other livestock which drink from water margins will help to control this species.	n/a	7.6.1
Novel	None recommended	n/a	n/a

5.5.7 Tall sedges *Carex* spp.

Greater pond-sedge *Carex riparia*

Sedges of the genera *Carex* are a large group of species, some of which can be problematic in the aquatic and riparian environment. A number of the larger, taller species, with rhizomes and grass-like leaves, are frequently encountered along watercourses and can require management. Such species include:

- greater pond-sedge *Carex riparia*
- lesser pond-sedge *Carex acutiformis*

They generally grow to a height of 1.5 m and can grow in waters up to 0.5 m in depth, although this varies between species. They will not tolerate deep water and they often just form fringes of marginal vegetation along the toe of the banks and do not encroach into deeper central parts of the channel. This can be very useful on watercourses for bank stability and preventing erosion; management should aim to retain a fringe of this species along the toe of the banks to help protect and stabilise them.

There are also a number of tussock-forming tall sedge species that can be found along watercourses (for example, greater tussock-sedge *Carex paniculata*, false fox-sedge *Carex otrubae*, cyperus sedge *Carex pseudocyperus* and tufted-sedge *Carex elata*). Due to their growth habit they tend not be problematic or require management.

Identification of sedge species can be difficult but can be done through examination of features including flowering parts, fruiting bodies (utricles), ligules. **Care should be taken to accurately identify the species prior to management as some species can be locally scarce** (see section 5.1).

Key problems caused

- In shallow, slow-flowing watercourses sedges can encroach into the channel, impede flows and reduce capacity.
- Rhizomes trap silt which extends the area that this species can colonise, further impeding flows.
- Dense stands can also impair fishing and other recreational activities.

Sedge *Carex* spp.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control (for one growing season); however, the rhizomes are not removed by many physical techniques and repeat management is necessary. De-weeding with a solid bucket provides longer-term control as rhizomes are removed.	Mid July to December	7.3 7.3.4
Chemical	Treatment with a glyphosate-based herbicide is effective and provides longer term control for several growing seasons (usually three) by being translocated to the rhizomes. Early season treatment can help to reduce the risk of summer flooding.	July to September May to June	7.4.1
Environmental	Manipulating water levels to more than 0.5 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 0.5 m should also help in preventing encroachment across the watercourse allowing just a fringe to develop along the bank toe; this has a number of benefits.	n/a n/a	7.5.4
Biological	If access is possible, livestock will graze sedges in riparian areas.	n/a	7.6.1
Novel	None recommended	n/a	n/a


© Shire Group of IDBs
Sedge *Carex* spp.


© Laura Thomas
Lesser pond-sedge *Carex acutiformis*

5.6 Emergent species – broad-leaved emergent species

Smaller emergent species of aquatic and riparian plant, with broad-leaves as opposed to long linear leaves, may also require management in certain situations. This group of species can cause problems by forming dense beds which can block channels and impede water flow. Many of these species are also quite fragile in nature and, during high water flows, fragments can become dislodged and block bridges, culverts and other structures, leading to localised flood risk issues.

Potentially problematic broad-leaved emergent species discussed below include:

- fool's water-cress *Apium nodiflorum*
- lesser water-parsnip *Berula erecta*
- water-cress *Rorippa nasturtium-aquaticum*
- water-soldier *Stratiotes aloides*
- Australian swamp stonecrop C*rassula helmsii*

Other broad-leaved emergent species can be found in aquatic and riparian habitats in the UK. However, these rarely require management and specific sections on these species are not included within this guide. Species that may be encountered include:

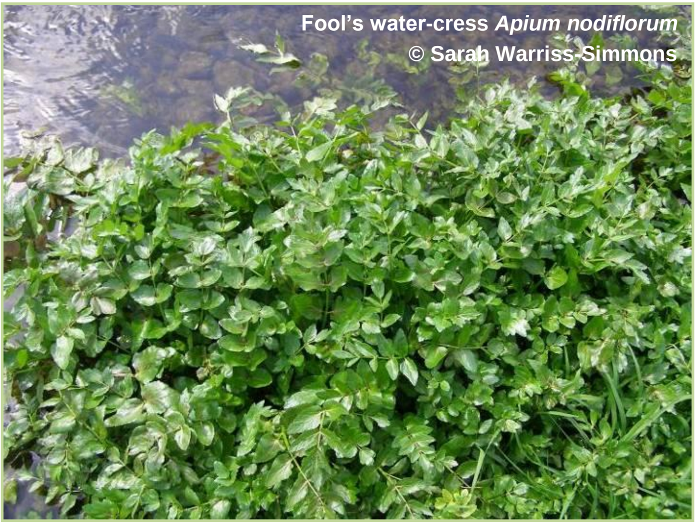
© Laura Thomas **Marsh Marigold *Caltha palustris***

- water-dropwort species *Oenanthe* spp. (most frequently hemlock water-dropwort *Oenanthe crocata*)
- marsh marigold *Caltha palustris*
- horsetail species *Equisetum* spp.

These species may be managed incidentally as a result of management targeted at other species. Care should be taken in doing this as cut horsetail *Equisetum* spp. material can be toxic if eaten and hemlock water-dropwort *Oenanthe crocata* is one of the most toxic plants in the country and livestock can be highly susceptible to poisoning, particularly where roots are exposed after management operations.

5.6.1 Fool's water-cress *Apium nodiflorum*

Fool's water-cress *Apium nodiflorum* is a marginal species of ditches and rivers in lowland areas. It can grow relatively large, with hollow stems up to 1 m in length, which grow along the ground. In faster-flowing waters, particularly chalk rivers, submerged patches can develop and it can be very abundant in this habitat. This species can be confused with lesser water-parsnip *Berula erecta* (see section 5.6.2) and water-cress *Rorippa nasturtium-aquaticum* (see section 5.6.3).


Fool's water-cress *Apium nodiflorum*
© Sarah Warriss-Simmons

Fool's water-cress *Apium nodiflorum* has complex leaf composed of 4–6 pairs of opposite leaflets along a central leaf stalk, with a single leaflet at the end. These leaflets have shallow, blunt teeth along the margins. They are also usually bright green in colour. The flowers of this species are tiny and white and are held on several branches that form an umbel, which emerges from where the leaf joins the stem.

This species is characteristic of nutrient-rich and disturbed areas, and readily colonises riparian habitats following erosion or disturbance as a result of management operations or flooding. It is a perennial species that dies back in winter and regrows the following spring, but it also grows from seed, and vegetatively from detached shoots which root very quickly.


© Sarah Warriss-Simmons
Fool's water-cress *Apium nodiflorum*

Key problems caused

- Can form dense stands which can choke channels, impeding water flows and reducing capacity.
- It is a fragile species which easily fragments by high water flows and can then block structures including bridges, sluices, weirs and screens.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control (one season only, and sometimes less than this) but regrowth from seeds and fragments will be rapid. As the watercourses in which this species is problematic are generally small, manual methods or de-weeding with a weed bucket are usually the most appropriate physical techniques to use.	Mid July to December	7.3 7.3.1 7.3.3
Chemical	Fool's water-cress is susceptible to glyphosate-based herbicides and control for two growing seasons can be achieved. This is more effective when undertaken later in the growing season.	July to September	7.4.1
Environmental	Fool's water-cress is intolerant of dense shade; a variety of shading methods should help to control this species. It also favours disturbed, nutrient-rich habitats; techniques which limit nutrient inputs to watercourses, such as buffer strips, point and diffuse pollution management, will reduce the vigour of stands in the long term. Reducing erosion pressures which provide areas which this species can readily colonise can also control this species.	n/a n/a	7.5.1 7.5.2 7.5.6
Biological	This species is very palatable to livestock and sustained grazing pressure should eliminate this species over a few years.	n/a	7.6.1
Novel	None recommended	n/a	n/a

Fool's water-cress *Apium nodiflorum* **© JBA Consulting**

5.6.2 Lesser water-parsnip *Berula erecta*


© Sarah Warriss-Simmons
Lesser water-parsnip *Berula erecta*

Lesser water-parsnip *Berula erecta* is a perennial species of ditches, rivers and lakes and marshes, frequently occurring in calcareous environments. While usually emergent in growth habit, it can also grow submerged in some cases, particularly where water flow is faster. It can grow in water up to 0.6 m deep, but it prefers water of 0.15–0.3 m in depth.

It has relatively long, grooved, hollow stems of 0.3–1 m in length, and it usually grows in a low-growing, sprawling habit. It has complex leaf composed of 7–10 pairs of opposite leaflets which are 2–6cm long and arranged along a central leaf stalk, with a single leaflet at the end. These leaflets have quite deep teeth along the margins. This species always has a pale ring-mark at the base of the stem (illustrated below).


Lesser water-parsnip *Berula erecta*
© Sarah Warriss-Simmons

The flowers of this species are tiny and white and are held on a few branches that form a small umbel (3–6 cm across) with branches that are only 1–3 cm long. This umbel emerges from where the leaf joins the stem.

This species can be confused with fool's water-cress *Apium nodiflorum* (see section 5.6.1) and water-cress *Rorippa nasturtium-aquaticum* (see section 5.6.3). The ring-mark on lesser water-parsnip *Berula erecta* stems is the key feature; this in particular distinguishes it from fool's water-cress *Apium nodiflorum*.

A similar, but much larger species, greater water-parsnip *Sium latifolium*, can also be found in riparian habitats. This species is scarce and included on the UK BAP. Management of this species should not be conducted unless it is part of a programme of encouraging establishment and growth of the plant and creating appropriate habitat conditions. It is a much larger and taller species (up to 2 m tall, with leaflets up to 15 cm), with a much more erect growth habit.

Key problems caused

- This species can form dense stands which can choke channels, impeding water flows and reducing capacity.
- It is a fragile species which easily fragments by high water flows and can then block structures including bridges, sluices, weirs and screens.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control (one season only, and sometimes less than this with rapid regrowth occurring from seeds and fragments). Repeat cuttings may be required in one season.	Before flowering to reduce seed dispersal	7.3
Chemical	Lesser water-parsnip is susceptible to glyphosate-based herbicides where leaves are emergent.	March to May (before flowering) Regrowth treated before end August	7.4.1
Environmental	Lesser water-parsnip is intolerant of shade, and a variety of shading methods should help to control this species. Manipulating water levels to more than 0.6 m for a prolonged period of time may help to control stands. Creating a deeper central channel of more than 0.6 m should also help in preventing encroachment across the channel.	n/a n/a n/a	7.5.1 7.5.2 7.5.4
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

5.6.3 Water-cress *Rorippa nasturtium-aquaticum*

Water-cress *Rorippa nasturtium-aquaticum*

Water-cress *Rorippa nasturtium-aquaticum* is a perennial wetland species with creeping stems (up to 1 m) and erect flowering shoots. Its leaves are dark green in colour and hairless.

It has complex leaf composed of a number of leaflets which are not arranged directly oppositely along the stem, but slightly alternately, with a single leaflet at the end. These leaflets vary in size with broader leaflets at the bottom (see photograph opposite for elongated upper leaves and below for broader basal leaves). The leaflets are also very rounded and untoothed. This species has small white flowers (4–6 mm across) and forms distinctive seed pods with two clear rows of seeds visible within the pod.

It is a species of streams and ditches, usually in running water.

This species can be confused with Fool's Water-cress *Apium nodiflorum* (see section 5.6.1) and lesser water-parsnip *Berula erecta* (see section 5.6.2). The much more rounded and slightly alternately arranged leaflets are the key diagnostic feature.

Key problems caused

- Can form dense stands which can choke channels, impeding water flows and reducing capacity.
- It is a fragile species which easily fragments by high water flows and can then block structures including bridges, sluices, weirs and screens.

Water-cress *Rorippa nasturtium-aquaticum*

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control (usually of one season only and sometimes less than this). Repeat cuttings may be required in one season.	Mid July to December	7.3
Chemical	Water-cress *Rorippa nasturtium-aquaticum* is susceptible to glyphosate-based herbicides.	June to September	7.4.1
Environmental	Increased shading, through a variety of methods, can be an effective control of this species.	n/a	7.5.1 7.5.2
Biological	Grazing by livestock may help to control the extent of this species, where access to the watercourse is possible.	n/a	7.6.1
Novel	None recommended	n/a	n/a


Water-cress *Rorippa nasturtium-aquaticum*
© JBA Consulting


Water-cress *Rorippa nasturtium-aquaticum*
© Laura Thomas

5.6.4 Water-soldier *Stratiotes aloides*

© Sarah Warriss-Simmons

Water-soldier *Stratiotes aloides*

Water-soldier *Stratiotes aloides* is an aquatic species that can be entirely submerged in growth habit (usually during the winter), sometimes floating, but in summer its leaves emerge above the water surface. It has leaves arranged in a large crown-like rosette that are rigid, long, narrow and pointed with spines along the margins. The leaves can be up to 50 cm in length and are also often translucent and brown-green in colour. Its flowers emerge individually above the water on stalks 5–8 cm tall. The flowers are three-petalled, white and 3–4 cm across.

This species is considered native to the east of England, where it is now localised in its distribution, but introduced elsewhere. It can be found in canals and ditches, and also fens and ponds. It is more frequent in calcareous environments. Management of this species in its natural range (east of ... on.

Key problems caused

- In localised areas it can form extensive stands which can reduce channel capacity.
- Extensive stands can also impair fishing and recreational activities.

Water-soldier *Stratiotes aloides*

© Laura Thomas

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective at achieving instant, short-term control. Care should be taken if hand cutting this species due to its spined leaf margins.	Mid July to December	7.3
Chemical	Glyphosate-based herbicides are effective on the emergent parts of this plant, but cannot be used when.	July to August	7.4.1
Environmental	None available	n/a	n/a
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

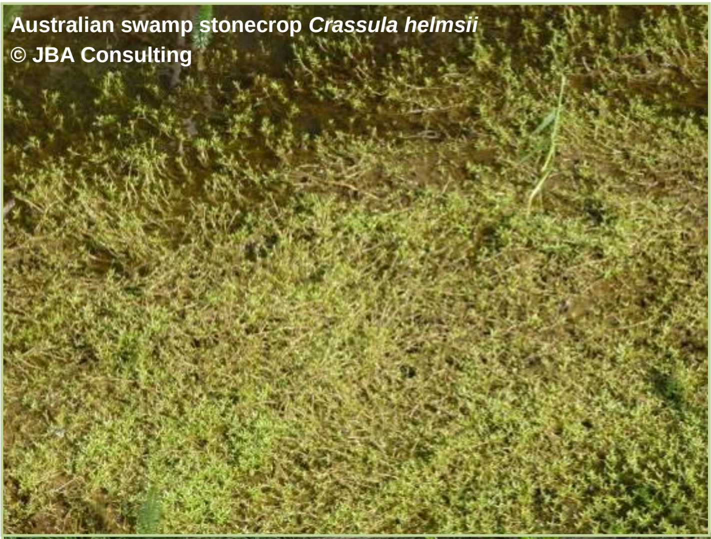
5.6.5 Australian swamp stonecrop *Crassula helmsii*

© JBA Consulting
Australian swamp stonecrop *Crassula helmsii*

Australian swamp stonecrop *Crassula helmsii* (also known as New Zealand pigmyweed) is a non-native, highly invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild. It was introduced into the UK in 1911 and sold as an oxygenating plant. It was first recorded in the wild in 1956 and is increasingly becoming problematic.

It will grow in a variety of habitats, from damp muddy margins to water 3 m deep and can be found in slow-flowing watercourses and in lakes and ponds. It can occasionally also be found in faster flowing waters.

It is highly tolerant of extreme environmental conditions (including shade, frost and drought) and has three distinct growth forms: terrestrial, emergent and submerged. It grows throughout the year and can regenerate from very small fragments.


Australian swamp stonecrop *Crassula helmsii*
© JBA Consulting


© Shire Group of IDBs
Australian swamp stonecrop *Crassula helmsii*

It has stems (up to 30 cm in length) which can either be erect or trailing in the water or on mud. Its leaves are short (4–15 mm), linear and fleshy. They are arranged oppositely along the stem and sometimes fuse at the base. Below the point where leaves attach (that is, the node), there is a dark ring.

Australian swamp stonecrop *Crassula helmsii* has whitish flowers with four petals, which are held on stalks.

Superficially this species can resemble water-starwort *Callitriche* species (see section 5.4.4), but water-starworts *Callitriche* spp. do not have fleshy leaves or the dark ring below the node. Water-starworts *Callitriche* spp. also have notched leaf tips whereas Australian swamp stonecrop *Crassula helmsii* does not.

Key problems caused

- This species is very difficult to manage.
- It can form very dense stands that can spread rapidly forming single-species stands which out-compete other native flora.
- Severe deoxygenation of waters can occur beneath dense stands of this plant.

Technique type	Applicability	Timing	Relevant sections
Physical	**Take care when controlling by physical means.** It is a very brittle plant which easily fragments by cutting and tearing and it can regenerate from tiny fragments which can cause spread of this species downstream. Dredging out material can be effective, as the plant is shallow-rooted. Extreme care should be taken to avoid spread of fragments. Dredged material should be piled in heaps and covered with thick black polythene sheeting or at least 20 cm of soil. Trials of mechanically excavating contaminated soil from drained areas and then burying it under plastic sheeting are underway in the Netherlands and Ireland.	n/a	7.3.4
Chemical	Australian swamp stonecrop can be susceptible to glyphosate-based herbicides, though this will not be effective if only submerged material is present. Retreatment is often required to ensure plant material not affected during the first attempt is treated. Mechanical removal of treated material is recommended to prevent deoxygenation of waters from decomposition, but care is needed to ensure fragments are not spread.	March to November	7.4.1
Environmental	While this plant is tolerant of dense shade, use of benthic barriers has been trialled and keeping plants covered for six months may be effective.	n/a	7.5.2
Biological	None recommended	n/a	n/a
Novel	Use of hot foam has been trialled. This technique is not effective when the plant is growing in water.	March to November	7.7.1
Integrated	Manipulation of water levels by de-watering areas where Australian swamp stonecrop is present can be effective when followed by chemical control.	As above	7.5.5 7.8

5.7 Algae

Algae are a widely diverse group of plants, with several thousand different species, which are classified botanically according to the colour of pigment they contain. They can occur in a wide range of aquatic and riparian habitats.

Algae can reproduce very rapidly, either from the release of spores or from regrowth from fragments, and as a result they can become quite problematic in a very short period of time. They are also often the first group of species to colonise a watercourse following disturbance or management operations.


© Judy England, Environment Agency
Unicellular green algae

Increasing nutrient levels in many watercourses has been reported to result in more frequent occurrence of algae problems and consequently a greater need for management. Consequently, as a general consideration, ensuring that a good population of other aquatic and riparian plant species are present and aiming to reduce nutrient inputs to watercourses, should help to reduce the problems caused by algae. Algae problems are most likely to occur when weather conditions are warm, during low flows, after pollution incidents or following management or engineering works.

Certain groups of algae are generally problematic in watercourses and require management. The groups of algae covered by this guide include:

- filamentous green algae
- stoneworts (charophytes)
- unicellular green algae and cyanobacteria

5.7.1 Filamentous green algae

Filamentous green algae are also commonly referred to as 'cott' or 'blanketweed'. Common genera of this group of algae, which can be problematic in watercourses, include:

- *Cladophora* – a large group that can occur in a wide range of habitats. Some species form floating spheres and others mats.
- *Enteromorpha* – primarily marine algae, but there are some freshwater species in this group. They usually consist of branches, tubes or sac-like structures.
- *Rhizoclonium* – common in a range of aquatic habitats, often entangled with other algae.
- *Spirogyra* – a large group found in freshwaters, which contains spirally arranged structures.
- *Vaucheria* – forms mats in either terrestrial or freshwater environments


Filamentous green algae *Cladophora* and *Enteromorpha*

The filamentous green algae species water net *Hydrodictyon reticulatum* can also be problematic in some situations, and has become increasingly common over recent decades.

Filamentous green algae form hair-like filaments, which can attach to the watercourse bottom and other plants, or can also form free-floating blankets on the water surface. Extremely large growths can rapidly appear, especially in warm weather and low flows. Nutrient input to watercourses and potentially climate change has increased the problems caused by filamentous green algae over recent years.

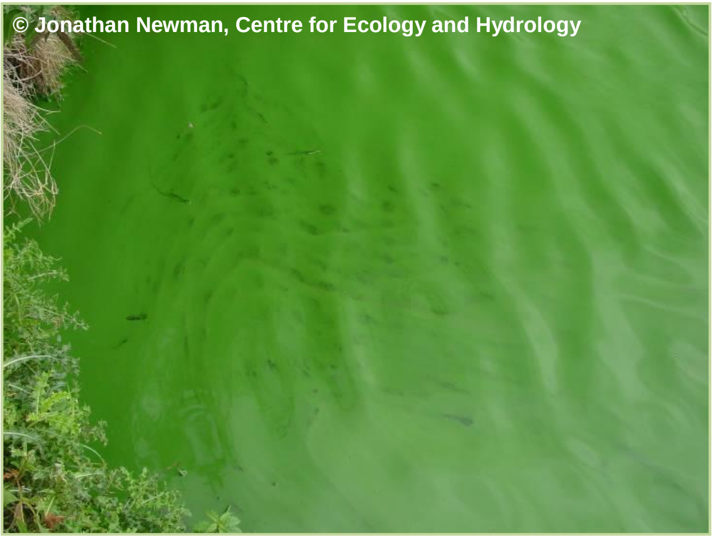
Filamentous green algae are a very problematic group of plants to manage in watercourses.

Key problems caused

- Large colonies and mats of algae can impede flows and block structures, particularly if they become detached and float downstream.
- Where large mats form, navigation and recreational activities including fishing and boating can be impeded.
- Deoxygenation of waters can occur as a result of extensive mats of filamentous algae, particularly as they decay or rise and float on the water surface.
- Filamentous algae can smother aquatic habitats and species and block out light to submerged species.
- They are sometimes considered to impair the visual amenity value of watercourses.
- Drinking water supplies can be tainted.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques generally have little impact on filamentous green algae as these leave fragments which continue to grow. The impact is very short term, particularly in warm weather when regrowth can be rapid.		
	Weed harvesters can be more effective than other physical techniques as large quantities can be removed.	Mid July to September	7.3.2
	Hand raking can be used on smaller infestations and on smaller watercourses.	Mid July to September	7.3.1
	Disposal can be an issue as harvested material does often not compost easily.		
Chemical	Barley straw and barley straw extract are effective in controlling filamentous green algae.	Early spring and autumn	7.4.2
Environmental	Dyes can be used to suppress growth by blocking out light available for photosynthesis.	Early spring and autumn	7.5.3
Biological	None recommended	n/a	n/a
Novel	Ultrasound can be used to control filamentous green algae.	n/a	7.7.2
	Electromagnetic water treatment is currently being developed to control infestations of filamentous green algae and may become a more feasible option in the future.	n/a	7.7.3

5.7.2 Unicellular green algae and cyanobacteria



Unicellular green algae consist of single cells that are microscopic but which at high concentrations make the water appear a turbid bright green.

Cyanobacteria are a separate group of organisms, formerly referred to as 'blue-green algae', which are also unicellular although some can form fine filaments.

Cyanobacteria can form dense blooms, particularly when temperatures are high, and are more common in stagnant and slow-flowing waters; in faster flowing waters they tend to get dispersed. These blooms are usually green or blue-green, but can also be purple or red. Once developed it may also look like a surface scum on the water. They also often have unpleasant odours.

Both unicellular green algae and cyanobacteria tend to occur in watercourses where nutrient levels are high and where other aquatic vegetation cover is limited, for example, after intensive management or engineering works.

Unicellular algae, both green and cyanobacteria, do not impact on the flow of watercourses. In some circumstances management may be required, particularly due to the toxicity and health risks associated with cyanobacteria.

Key problems caused

- Many unicellular algae, both green and cyanobacteria, can produce toxins which are hazardous to wildlife, livestock, pets and humans, causing severe illness and in some cases death. **Extreme care should be taken when working in waters where blooms are present.**
- They can have an unpleasant smell.
- They are sometimes considered to impair the visual amenity value of watercourses.
- Drinking water supplies can be tainted.

Technique type	Applicability	Timing	Relevant sections
Physical	None available	n/a	n/a
Chemical	Barley straw and barley straw extract are effective in controlling unicellular green algae and cyanobacteria.	Early spring and autumn	7.4.2
Environmental	Dyes can be used to suppress growth by blocking out light available for photosynthesis.	Early spring and autumn	7.5.3

Technique type	Applicability	Timing	Relevant sections
Biological	Some invertebrates such as the water flea *Daphnia* spp. feed on unicellular algae and can be quite effective in controlling algal blooms. The use of this as a management technique is limited as increasing the population to have any real impact would probably require removing fish.	n/a	7.6
Novel	Ultrasound can be used to control unicellular green algae and cyanobacteria.	n/a	7.7.2
	Electromagnetic water treatment is currently being developed to control unicellular green algae and cyanobacteria and may become a more feasible option in the future.	n/a	7.7.3

Cyanobacteria *Anabaena flos-aquae and circinalis*

© Judy England, Environment Agency

5.7.3 Stoneworts (charophytes)

Chara spp.

Stoneworts or charophytes are among the largest and most complex green algae. They are a group of submerged freshwater species, characteristic of disturbed habitats and are often the first group to colonise watercourses following management or engineering operations. They are also generally species found in areas of high water quality. The group contains six genera, the most frequently encountered of which are *Chara* and *Nitella*.

As a complex group of algae, they have stems with branches in a number of whorls and can resemble submerged vascular plants.

Stoneworts do not usually requiring management though, in certain circumstances, they can be problematic. Stonewort beds are ecologically important supporting a number of aquatic invertebrate species and also fisheries. **Management should only be undertaken where absolutely necessary.**

Key problems caused

- They can form a dense carpet which restricts colonisation by other aquatic plant species.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical techniques are effective in controlling this group of algae. Some regrowth will occur from cut material and also the following spring.	Mid July to September	7.3
Chemical	None available	n/a	n/a
Environmental	Stoneworts are intolerant of dense shade. Shading, through a variety of methods, is an effective control method. Dyes can be used to suppress growth by blocking out light available for photosynthesis. Stoneworts are often out-competed by other submerged and floating-leaved plants. Encouraging these may limit stonewort populations, but other aquatic plant species may then require management.	n/a n/a n/a	7.5.1 7.5.2 7.5.3 7.5.1
Biological	None available	n/a	n/a
Novel	None recommended	n/a	n/a

5.8 Non-native invasive bank species

Within the aquatic and riparian environment a number of non-native invasive species are also problematic. The European Commission has stated that invasive species are the second biggest threat to biodiversity after habitat destruction (Newman 2009). The annual cost of invasive, non-native species management on waterways in Britain has been estimated at £21.86 million (Williams et al. 2010).

Three non-native invasive species are particularly problematic along the banks of watercourses in the UK. While they are really terrestrial plants, they are associated with waterways as these provide corridors along which they can spread. They are:

- Japanese knotweed *Fallopia japonica*
- Himalayan balsam *Impatiens glandulifera*
- Giant hogweed *Heracleum mantegazzianum*

All three are listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) making it an offence to 'plant or otherwise cause to grow in the wild'.

Non-native invasive plants, such as those listed above and those discussed in previous sections, give increasing cause for concern. These species are leading to a reduction in local plant biodiversity and can also cause economic damage, and for some species, present a health hazard to humans.

Any management of non-native invasive species, both within the watercourse and on the banksides, needs to consider appropriate biosecurity protocols. There are also issues associated with waste disposal and contaminated material when working with these species.

There are other non-native invasive species that may also be encountered in the riparian environment and may constrain management operations in watercourses. However, these species do not create as widespread problems as those listed above and therefore specific sections are not provided in this guide. Species falling in this category include giant rhubarb *Gunnera tinctoria* (see photograph) and giant butterbur *Petasites japonica*; only the former is listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended).

Giant rhubarb *Gunnera tinctoria*

Giant rhubarb is a fast-growing species with very large leathery leaves on stems that can grow up to 2 m in height.

Giant butterbur *Petasites japonica* has slightly smaller, kidney-shaped leaves, but can also reach heights of 2 m. Both these species tend to grow on damp soils, with riparian habitats providing suitable environments in which they can grow.

5.8.1 Japanese knotweed *Fallopia japonica*

Japanese Knotweed *Fallopia japonica* was brought to the UK in the mid-19th as an ornamental garden plant. It was first found in the wild in 1886 and since then it has rapidly colonised riverbanks and areas of waste ground. It is a non-native, highly invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild.

Japanese knotweed *Fallopia japonica* is a perennial species, growing from rhizomes to a height of 3 m in summer with stiff bamboo-like stems, which often remain standing into the winter months. It has large, oval-triangular leaves, with a distinct point. The leaves are held on reddish stems in an alternate arrangement which gives the stem a zigzag nature. Masses of small creamy-white flowers are produced in late summer but do not, at present, produce viable seed. The plant is spread from broken fragments of stems or rhizomes, often via contaminated topsoil or from cut or detached material floating downstream in watercourses.

Soil and other material containing Japanese knotweed *Fallopia japonica*, if taken away from their point of origin, is considered to be 'controlled waste' under section 33/34 of the Environmental Protection Act 1990 and carries a 'duty of care' regarding its disposal in an appropriate manner to prevent environmental pollution or harm to health. If material is taken off-site it should be taken to an appropriately licensed landfill site.

Strict biosecurity measures are critical when managing this species.

Key problems caused

- This species can form dense stands along watercourse banks impeding access for management.
- Dense stands out-compete and shade out native riparian species. In winter these bare banks are at risk of erosion.
- The rhizomes can penetrate and damage stone and concrete structures and embankments.

Technique type	Applicability	Timing	Relevant sections
Physical	**Do not flail mow this species** as it can regrow from small fragments. Physical techniques can be undertaken on this plant, but should only use simple blades to create a clean cut with no fragmentation. Physical techniques are only likely to have a short-term impact on small, localised stands and are not generally effective alone. Cut material should be collected and burnt or disposed of at a licensed landfill. Frequent and repeated cutting will reduce the vigour of this species over several years. **Extreme care must be taken to prevent fragmentation and spread –** contaminated material should not be taken off-site if it can be avoided and fragments should not be allowed to enter a watercourse and float downstream.	June to October	7.3.1
Chemical	Glyphosate-based herbicides are effective on this species. Spraying is most effective during the flowering period. More effective control can be achieved by applying herbicide to the top and underside of the leaves. Treatment for at least two years is likely to be required, with any regrowth spot treated. Stem-injection herbicide application methods can be used on this species.	August to October	7.4.1
Environmental	Once established there are no environmental techniques for this species. Banks that are vegetated with a dense sward or fringes of tall emergent vegetation are less likely to offer suitable sites for this species to establish.	n/a n/a	
Biological	Grazing of shoots by horses, donkeys, sheep and goats may keep the plant in check but will not eradicate it. Care also needs to be taken when grazing infested areas as plant fragments could be trampled and dispersed by animals. No specific control agent is yet available – CABI is conducting research (www.cabi.org/projects/project/1324).	n/a	7.6.1
Novel	None recommended	n/a	n/a
Integrated	Integrated control options are usually the most effective, using combinations of physical techniques and glyphosate-based herbicides.	As above	7.8

Further information on the management of Japanese knotweed

- The Japanese Knotweed Code of Practice (www.gov.uk/japanese-knotweed-giant-hogweed-and-other-invasive-plants)

A number of other non-native knotweed species similar to Japanese knotweed *Fallopia japonica* may be found in the UK in a riparian environment including:

- giant knotweed *Fallopia sachalinensis*
- the hybrid *Fallopia japonica x sachalinensis* – sometimes known as Bohemian knotweed *Fallopia x bohemica*

Both giant knotweed *Fallopia sachalinensis* and the hybrid are listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended).

5.8.2 Himalayan balsam *Impatiens glandulifera*

Himalayan balsam *Impatiens glandulifera* © JBA Consulting

Himalayan balsam *Impatiens glandulifera* is a non-native, highly invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild. It was introduced as an ornamental garden plant and following escape has rapidly colonised the banks of rivers and other water bodies.

Himalayan balsam *Impatiens glandulifera* is an annual plant which grows to approximately 2 m in height, forming dense stands. Because of its annual habit and ready regrowth from seed, any management carried out after the seed has set will be ineffective in the subsequent year. It has reddish stems and oval leaves with distinct teeth which are arranged around the stem in whorls of three. It has large, trumpet-shaped, pink flowers which can vary considerably in depth of colour, with some almost white and others deep purple-pink.

The seed pods of this species are explosive to touch and can spread seeds up to 7 m from the plant. Management should be undertaken before the plant has set seed to avoid the risk of spread from this mode of dispersal.

There are two other non-native balsam species in the UK, orange balsam *Impatiens capensis*, which is a smaller plant with orange, red-spotted flowers, and small balsam *I. parviflora* which is again a much smaller plant with pale yellow flowers. Both species have alternately arranged leaves and should not be confused with Himalayan balsam. There is also a native balsam species in the UK: touch-me-not balsam *Impatiens noli-tangere* which is similar to small balsam with yellow flowers.

Key problems caused

- It forms dense stands which suppresses the growth of native riparian species.
- As an annual plant, the dense stands die back in winter, leaving banks bare and more prone to erosion during high winter flows.

Himalayan balsam *Impatiens glandulifera*

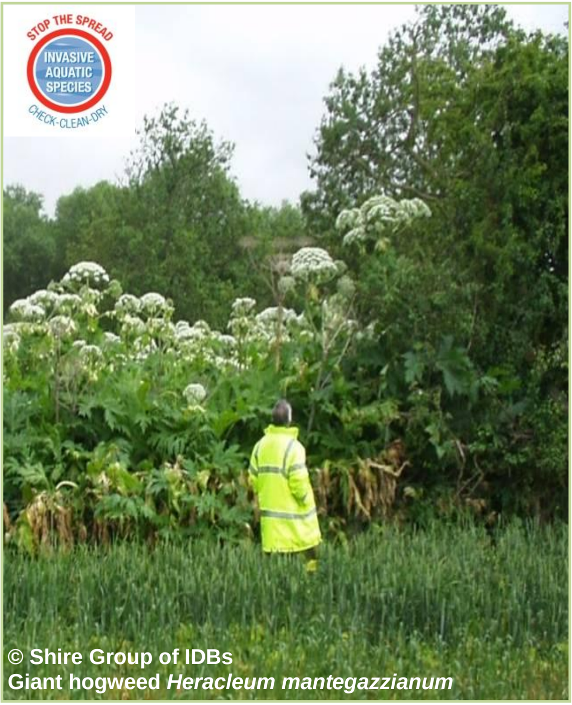
© Sarah Warriss-Simmons

Technique type	Applicability	Timing	Relevant sections
Physical	A number of physical techniques, manual and mechanical, can be effective for this species. It is easily cut by hand or machine, but access can be problematic where it grows in among trees and scrub. All cutting should be undertaken below the first node to prevent regrowth. Regular and frequent mowing will also help to control this species, as long as flowers and seed pods are prevented from forming. Hand pulling is also effective as it is a shallow-rooted species. As the seed bank can remain viable for 18 months, a minimum of two years of physical control will be needed to eradicate the plant, assuming there is no risk of recolonisation from upstream sources.	March to June	7.3 7.3.5 7.3.1
Chemical	Glyphosate-based herbicides are effective on this species. Two to three years of repeat treatment may be required.	April to June (before flowering)	7.4.1
Environmental	There are few environmental techniques available, but maintenance of a dense grass sward with regular management should help to prevent germination and growth of seedlings.	n/a	n/a
Biological	Grazing by cattle and sheep is effective through the growing season. No specific control agent is yet available – CABI is conducting research (www.cabi.org/projects/project/1352).	n/a	7.6.1
Novel	None recommended	n/a	n/a

Himalayan balsam *Impatiens glandulifera*
© JBA Consulting

5.8.3 Giant hogweed *Heracleum mantegazzianum*

Giant hogweed *Heracleum mantegazzianum* was introduced into Britain in 1893 as an ornamental plant. It is now naturalised on waste land and river banks. It is a non-native, highly invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended) and it is an offence to plant or cause its spread in the wild.



© Shire Group of IDBs
Giant hogweed *Heracleum mantegazzianum*

Giant hogweed *Heracleum mantegazzianum* contains a toxic chemical which sensitises skin and leads to severe blistering when exposed to sunlight (a reaction which can recur for many years). **Potential risks to health must be taken into account when working with this species.**

It has a red-spotted stem which can be 0.1 m across, with lobed leaves up to 1 m with very sharp, pointed lobes. It has small whitish-pink flowers which are held on small branches to form an umbel; these can be up to 0.5 m across. It should not be confused with the native hogweed *Heracleum sphondylium*, which is a significantly smaller plant, growing only up to 2 m, with less angular lobed leaves.


© JBA Consulting
Giant hogweed *Heracleum mantegazzianum*

Giant hogweed *Heracleum mantegazzianum* is a vigorous perennial plant which takes 3–4 years to mature. Seedlings appear in February, producing immature plants, reaching 0.4 m in their first year. Foliage dies back in September/ October and subsequent growth from tap roots is very rapid in the second and third years. Flowering stalks start to elongate in May, with peak flowering in June/ July. In its fourth year of flowering, plants can reach 4–5 m in height and disperse 50,000–100,000 viable seeds per plant. Seeds that fall into water are spread downstream resulting in new stands of this species.

The effective control of giant hogweed *Heracleum mantegazzianum* must aim to prevent seed production by removing flowering heads as soon as possible, combined with ongoing management to remove the seed bank until it is exhausted.

Key problems caused

- This species establishes dense stands that displace and suppress the growth of native flora.
- Loss of natural bank vegetation can lead to increased potential for erosion during high winter flows.
- Plant is toxic and a health and safety risk.

If taken away from their point of origin, soil and other material containing giant hogweed *Heracleum mantegazzianum*, is considered to be 'controlled waste' under section 33/34 of the Environmental Protection Act 1990 and carries a 'duty of care' regarding its disposal in an appropriate manner to prevent environmental pollution or harm to health.

Technique type	Applicability	Timing	Relevant sections
Physical	Physical control techniques are effective, but require implementing regularly.		7.3
	Mechanical cutting before flowering provides short-term control but regrowth will be rapid. Cutting after flowering has no benefit, but to remove dead stems.	May to June	
	Cutting may also stimulate flower and seed production.		
	Mowing 2–3 times during the growing season hinders regrowth but will not eradicate this species.		7.3.5
	Manually cutting the roots with a spade at least 10 cm below ground level to ensure damage to the rootstock can kill the plant completely or at least reduce its chances of regrowth.		7.3.1
	Appropriate health and safety measures must be taken and protective clothing worn when physically managing this species.		
Chemical	Glyphosate-based herbicides can be effective, but should be applied early in the season to prevent flowering. Repeated treatments may be necessary within the same year and also subsequent growing seasons to control regrowth from the seedbank. Stem injection can be undertaken for this species.	March to May	7.4.1
Environmental	None available	n/a	n/a
Biological	Grazing by cattle, sheep, pigs or goats throughout the growing season will suppress growth, but does not eradicate it.	n/a	7.6.1
Novel	None recommended	n/a	n/a

6. Watercourse type classification

6.1 Introduction

To decide how best to manage a watercourse it is necessary to understand the watercourse type. This will ensure appropriate techniques are used and that their effect is not detrimental to the watercourse and its WFD status.

Watercourse typology can be related to aquatic and riparian vegetation as the properties, characteristics and functioning of UK watercourse types defines the hydraulics, sediment characteristics and dynamics of the system. This can then be applied to vegetation communities as different species thrive in different environments. The interaction between vegetation and geomorphology create the natural diverse and dynamic habitat of UK watercourses and these processes are fundamental to achieve WFD good ecological status.

Some of the strongest interactions between vegetation and geomorphology would naturally be found in lowland rivers, with the vegetation determining channel form. Heavy modification has now occurred in many of these lowland wetland systems, such as in the Somerset Levels, East Anglia and Lincolnshire. Rivers on bedrock rarely support dense in-stream vegetation in the UK as there is nowhere for the plants to root.

Distinguishing between different geomorphic watercourse types can sometimes be difficult. This chapter makes this process easier and provides links between the most common watercourse classifications and geomorphic watercourse types commonly used.

6.2 Background to watercourse type classification

Different approaches exist for classifying rivers and other watercourse types in the UK, which are primarily based on ecological and vegetative characteristics. One of the most widely used approaches is the Joint Nature Conservation Committee (JNCC) classification (Holmes et al*.* 1999). This classification identifies the watercourse types in relation to ecology and the aquatic plants present. The approach built on and used a method developed by Holmes (1983, 1989) and Holmes et al. (1998) to provide a robust classification for wide application across the UK. This method has been further refined by the JNCC (2005) to monitor the condition of SSSI and SAC sites (see Table 6.1).

A further approach which links species to watercourse type is the *Type Specific Reference Condition Descriptors for Rivers in Great Britain* developed by the WFD UK Technical Advisory Group (UKTAG) (see Table 6.2). However, this river typology approach is difficult to link to functional river types due to the parameters the classification has used to define the river types, which are geology, altitude and catchment area.

Table 6.1 JNCC river types

Group	Type	JNCC general description
A	I	Lowland rivers with minimal gradients. Predominantly in south and east England, but may occur wherever substrates are soft and chemistry enriched.
	II	Rivers flowing in catchments dominated by clay.
	III	Rivers flowing in catchments dominated by soft limestone such as chalk and oolite.
	IV	Rivers with impoverished vegetation, usually confined to lowlands and mainly in England.
B	V	Rivers of sandstone, mudstone and hard limestone catchments in England and Wales, with similar features to those of Type VI.
	VI	Rivers predominantly in Scotland and northern England in catchments dominated by sandstone, mudstone and hard limestone; substrates usually mixed coarse gravels, sands and silts mixed with cobbles and boulders.
C	VII	Mesotrophic rivers where fine sediments occur with boulders and cobbles, so a mix of bryophytes and higher plants is typical; often downstream of Type VIII communities.
	VIII	Oligo-mesotrophic, fast-flowing rivers where boulders are common and bryophytes typify the plant assemblages; intermediate, and often found between Types IX and VII.
D	IX	Oligotrophic rivers of mountains and moorlands where nutrient and base levels are low; bedrock, boulders and coarse substrates dominate.
	X	Ultra-oligotrophic rivers in mountains, or streams flowing off acid sands; substrates similar to Type IX but often more bedrock.

Table 6.2 UKTAG river classification

	Altitude <200 m	Altitude 200–800 m
Catchment size <100 km^2	**River Type 1: Siliceous** Morphology: Small streams, range of slopes. Diverse substrate types linked to flow velocity. Pebbles and cobbles tend to dominate in faster reaches, but more depositional environments with gravel, sand and silt may occur in the downstream sections. Hydrology: Low baseflow index. Low groundwater connectivity. Rapid hydrological response.	**River Type 10: Siliceous** Morphology: Ubiquitous in upland areas. Eroding turbulent upper reaches and depositing lower reaches with runs, glides, riffles and pools. Very diverse substrate and bedrock. Hydrology: Low baseflow index. Poor groundwater connectivity. Relatively rapid hydrological response, increased in smaller catchments.
	River Type 2: Calcareous Morphology: Variable slope and flow velocity. Diverse substrate types. Stony in upper reaches, gravels, sands and silts in the less steep sections. Hydrology: High baseflow index. Good groundwater connectivity. Relatively rapid hydrological response to rainfall events.	**River Type 11: Calcareous** Morphology: Small to medium size rivers. Variable, occasionally turbulent, flow. Fine sand and silt to gravel or cobbles. Riffles, runs and some pools present, depositional slower flowing sections downstream. Turbulent erosional upper sections. Hydrology: High baseflow index. Good groundwater connectivity. Delayed and subdued hydrological response, increased in small catchments.
	River Type 3: Organic Morphology: Small streams subject to peat deposition. Deeper slow flowing areas covered in fine particulate peat (silt in England), while faster flowing areas have sand or gravel substrate. Runs and glides. Hydrology: Organic catchments in Scotland. Show relatively rapid response to rainfall events. English and Welsh rivers more dependent on groundwater inputs, with a less rapid response to rainfall.	**River Type 12: Organic** Morphology: Small to medium size rivers flowing through peat dominated landscape. Slow flowing areas may be covered in fine particulate peat, while faster flows may have a sand, gravel or cobble substrate. Upper reaches will be erosional in nature. Hydrology: Low baseflow index. Relatively rapid response. Time-to-peak and recession to baseflow relatively rapid.
Catchment Size 100–1,000 km^2	**River Type 4: Siliceous** Morphology: Small rivers. Relatively shallow slopes predominate. Mostly cobble and gravel substrates. Hydrology: Low baseflow index. Relatively rapid hydrological response linked to catchment size.	**River Type 13: Siliceous** Morphology: Lower and middle reaches of medium sized rivers, in upland areas. Eroding and depositing zones with runs, riffles and pools. Sand, gravel, cobbles and boulders. Hydrology: Low baseflow index. Poor connectivity with groundwater. Relatively rapid hydrological response.
	River Type 5: Calcareous Morphology: Includes many chalk streams, mostly shallow slopes. Variable width. Predominantly depositional environment (gravels and silts). Hydrology: High baseflow index. Significant groundwater connectivity. Delayed and subdued hydrological response.	**River Type 14: Calcareous** Morphology: Shallow slopes. Pebble or gravel substrates. Hydrology: High baseflow index. Good groundwater connectivity. Subdued hydrological response to rainfall events.

Catchment size >1,000 km²	Altitude <200 m	Altitude 200–800 m
	River Type 6: Organic Morphology: Small to medium sized rivers. Depositional. Runs and riffles. Sand and gravel to cobbles and boulders. In England slopes are very low, and the substrate dominated by silt. Hydrology: Organic catchments in Scotland show relatively rapid response to rainfall events. English and Welsh rivers more dependent on groundwater inputs, with a less rapid response to rainfall.	**River Type 15: Organic** Morphology: Medium sized rivers, flowing through peat dominated landscape. Slow flowing areas may be covered in fine particulate peat, while faster flows may have a sand, gravel or cobble substrate. Hydrology: Low baseflow index. Relatively rapid response, slightly extended time-to-peak and slower recession to baseflow.
	River Type 7: Siliceous **Morphology:** Mainly shallow slopes. Variable width. Variable substrates commonly gravel and cobbles. **Hydrology:** Low baseflow index. Relatively rapid response subdued in largest catchments moderates this response.	**River Type 16: Siliceous** **Morphology:** Meandering depositional. Bars runs, glides, riffles and pools. Sand, silt, gravel cobbles and occasionally boulders. **Hydrology:** Low baseflow index. Relatively rapid hydrological response reduced in larger catchments.
	River Type 8: Calcareous **Morphology:** Includes many chalk rivers. Low slope slow flows. Extensive meanders, with ox-bows and cut-off channels. A diverse range of substrates. Depositional processes dominate. Frequent gravel and silt beds **Hydrology:** High baseflow index. Significant groundwater connectivity. Delayed and subdued hydrological response.	**River Type 17: Calcareous** **Morphology:** Shallow slopes. Highly variable width and depth. Extensive meanders and floodplain wetlands in the lower reaches. Wide range of substrates –increasingly silty downstream. **Hydrology:** High baseflow index. Good groundwater connectivity. Subdued hydrological response. Extended time-to-peak and slow recession.
	River Type 9: Organic **Morphology:** Closely associated with floodplain wetlands, with extensive meanders, very slow flows. Depositional processes dominate channel and floodplain. **Hydrology:** Baseflow dominated. Dependence on groundwater. Extensive flooding into the wetlands occurring at time of high winter flows.	**River Type 18: Organic** **Morphology:** Preponderance of eroding habitats. Bedrock and boulders in the steeper more turbulent areas. Cobbles and gravel below the areas of extreme erosion. **Hydrology:** Low baseflow index. Poor groundwater connectivity. Rapid response to rainfall events. Hydrograph time-to-peak and recession to baseflow will still be relatively speedy.

Geomorphic watercourse typologies are key to understanding and managing UK watercourse. Table 6.3 provides an overview of the different geomorphic water bodies found in England and Wales. This categorisation system will be used throughout this guide.

Table 6.3 Summary of geomorphic watercourse type

Type	Photograph	Key features
Step pool channel		• Channel-spanning pools • Boulder or bedrock steps • Often also has rapids • Some fine sediment
Bedrock channel		• Channel dominated by boulders and large cobbles • Bedrock outcrops • No pools or riffles • Very little or no bed sediment
Wandering channel		• Gravel bed and large gravel features (for example, gravel bars) • Characteristics similar to active single-thread systems but generally more active • Wide valley floor allowing lateral movement
Active meandering channel		• Low sediment supply for point bars • Often sand and gravel dominated dynamic channels • Less lateral movement than wandering channels
Pool riffle channel		• Characteristics of both wandering and active single-thread channels • Sand and fine gravel • Less dynamic than wandering channels
Plane bed channel		• Dominated by cobbles and gravels • Few depositional features • Uniform, shallow flow

Type	Photograph	Key features
Inactive single thread channel		• Less dynamic channels • Resistant bed and banks (often clay soils) • Often sinuous incised planform • Poor in-channel morphology with low level of activity
Canal/ reinforced drainage channel		• Artificially reinforced banks dominate this class • Little flow velocity • Will often have a 'tow path' adjacent to the channel
Modified urban watercourse		• Artificial bank profiles dominate this class • Often the bed will be modified and the channel heavily managed
Ditch/ small drain		• Mainly found in lowland areas with low gradient • The channel will often be narrow and deep compared to the width • Low energy channels
Artificial drainage channel		• Mainly found in lowland areas with low gradient • Deposition will be dominated by fine sediment • Gravels will be uncommon • Low energy channels
Photographs © JBA Consulting		

6.3 Defining geomorphic watercourse types

This section describes in more detail the geomorphic watercourse types outlined in Table 6.3. Appendix C summarises the linkages between this classification and the systems developed by the JNCC and UKTAG.

6.3.1 Step pool channel

Step pool river types are generally created by boulder clasts or bedrock layers forming steps separated by pools. The pools often contain finer sediments/ gravels due to the low energy conditions and channel stability is generally high, meaning little erosion occurs, particularly in the presence of bedrock. The channel gradient is usually steep and floodplain connectivity is poor, with channels often located in confined valleys, creating high energy conditions able to transport gravels, pebbles and cobbles during high flows. This leaved larger material, such as boulders, to be stored.

As step pool channels are often confined meaning lateral movement is restricted, contain large bed material with frequent bedrock and have limited channel scouring, they are less likely to be sensitive to channel alteration or increased sediment mobilisation as a result of vegetation management techniques.

Figure 6.1 Step pool channel watercourse type

6.3.2 Bedrock channel

Bedrock channels have a significant coverage of bedrock within the channel and the floodplain, providing very stable channel conditions. They are usually found in more upland areas, where gradients are high, giving significant energy meaning little sediment is stored, leaving the bedrock layer. As bedrock dominated channels are stable and confined in nature with very little sediment deposition exhibited, they will not be sensitive to channel alteration or increased sediment mobilisation as a result of vegetation management techniques.

Figure 6.2 Bedrock channel watercourse type

6.3.3 Wandering channel

Wandering river types are often found in moderate gradient systems where sediment loads are high (often of gravels, pebbles and cobbles), giving responsive channel conditions. Bank erosion can be significant where banks are weak, resulting in channel switching as it migrates across the valley floor over time. Depositional features are often large, resulting in heightened bank erosion as features grow, which is assisted by moderate floodplain connectivity.

As wandering systems contain extensive depositional areas and are dominated by lateral movement, they can be sensitive to channel alteration or increased sediment mobilisation which can arise and cause damage if an inappropriate vegetation management technique is used. For example, artificially narrowing a channel could lead to significant channel bed and bank erosion and extensive sediment mobilisation.

Figure 6.3 Wandering channel watercourse type

6.3.4 Active meandering channel

Active meandering channels are generally lowland river types with a relatively low gradient (although generally steeper than inactive single thread). Lateral movement is common, though less significant than wandering channels, and bank erosion can readily occur in flood conditions. Depositional features are small to moderate in size and are mainly composed of gravels and finer sediment, often due to lower sediment loads and restricted lateral movement. Floodplain connectivity is usually moderate, allowing gravel deposition to occur and minimising bed incision. Energy levels and sediment transport rates are lower compared to wandering systems, but are energetic enough to erode, transport and deposit during higher flows.

These channel types are generally more stable than wandering systems. However, the channel may be sensitive to alteration or increased sediment mobilisation if an inappropriate technique is used. For example, modifications to the channel flow regime and velocities could lead to increased bank erosion and sediment mobility.

Figure 6.4 Active meander channel watercourse type

6.3.5 Pool riffle channel

Pool riffle rivers are similar to active meandering channels in character and in terms of form and process, with the riffles generally composed of gravels and pebbles in more moderate gradient sections of river. Deeper, lower energy pools form behind the riffles.

Pool riffle systems are generally more stable than wandering systems. However, the channel may be sensitive to bed and bank alteration or increased sediment mobilisation if an inappropriate vegetation management technique is used.

Figure 6.5 Pool riffle channel watercourse type

6.3.6 Plane bed channel

Plane bed river types are generally dominated by cobbles and gravels, with very few depositional features such as gravel bars. They have an extended run flow type (with a rippled surface) with a constant, shallow flow depth. They generally have a moderate gradient with little fine sediment infilling of the channel bed. Sediment transport rates are high and gravel feature growth limited as a result of the energy levels, limited storage and stable banks which limit bank erosion.

Plane bed systems are generally more stable than wandering systems. However, the channel may be sensitive to bed and bank alteration or increased sediment mobilisation if an inappropriate vegetation management technique is used.

Figure 6.6 Plane bed channel watercourse type

6.3.7 Inactive single thread channel

Inactive single thread channel types are generally found in lowland areas with a relatively low gradient. This type is characterised by long deep pools dominated by fine sediment. Gravel features are uncommon or poorly developed due to low energy conditions. Flow energy levels are low, creating monotonous glide flow characteristics in many locations (deep, slow moving water). The banks of the channel are often cohesive, restricting lateral movement due to bank material type or deep root mats within the banks. The channel is often disconnected from the floodplain and displays signs of overdeepening.

Inactive single thread systems are generally stable. However, the channel type may be at risk of damage if an inappropriate technique is used. For example, inappropriate grazing may significantly increase fine sediment inputs to the channel leading to excessive fine sediment deposition on the channel bed.

Figure 6.7 Inactive single thread watercourse type

6.3.8 Canal/ reinforced drainage channel

Canals and reinforced drainage channels are defined by their artificial and reinforced banks. Flows and levels will be typically static meaning very little change to in-channel morphological features, with high amounts of fine sediment accumulation in the channel.

Canals/ reinforced drainage channels are stable systems. However, instability may result from using an inappropriate vegetation management technique such as cattle grazing too close to the channel edge causing poaching and enhancing fine sediment inputs into the watercourse.

Figure 6.8 Canals/ reinforced drainage channel watercourse type

6.3.9 Modified urban watercourse

Modified urban watercourses can have man-made artificial banks or channel beds, and in some cases both. These types of watercourse are found in urban areas. Velocities can sometimes be high and deposition would frequently be low. They are often heavily managed for flood risk management purposes.

Modified urban watercourses are generally stable systems as a result of historic modifications to the channel. A lack of maintenance can lead to system instability and long term deterioration.

Figure 6.9 Modified urban watercourse type

6.3.10 Ditch/ small drain

Ditches and small drains are mainly found in lowland areas with low gradients, giving low energy flow conditions and often high rates of fine sediment accumulation. These types of channel are often narrow – frequently the channel width will be approximately equivalent to the depth from the floodplain.

Ditches/ small drains are generally stable systems due to the lower energy conditions. However, sediment instability and fine sediment mobilisation may result from using an inappropriate vegetation management technique such as unsuitable de-weeding methods.

Figure 6.10 Ditches and small drains watercourse type

6.3.11 Artificial drainage channel

Artificial drainage channels are mainly found in lowland areas with low gradients, giving low energy flow conditions. They often have a straight planform. Deposition is dominated by fine sediment and gravels are uncommon. Banks are not normally reinforced. Channels of this type are normally larger than ditches/ small drains, with the channel width greater than the channel depth.

Artificial drainage channels are stable systems. However, increased fine sediment inputs to the channel may result from using an inappropriate vegetation management technique such as grazing up to the channel banks.

Figure 6.11 Artificial drainage channel watercourse type

6.4 Selecting geomorphic watercourse type

It is vital to ensure the correct watercourse type is determined before undertaking any form of channel or bank management. Damage to watercourse processes could occur by incorrectly identifying the watercourse type and subsequently applying an inappropriate management technique, The flowchart shown in Figure 6.12 is designed to help watercourse managers identify different watercourse types. The flowchart guides users to the most appropriate watercourse typology through a series of simple questions based on channel type, size and process. Simple explanations of the key watercourse characteristics are provided on the flowchart and Section 6.3 provides more detail.

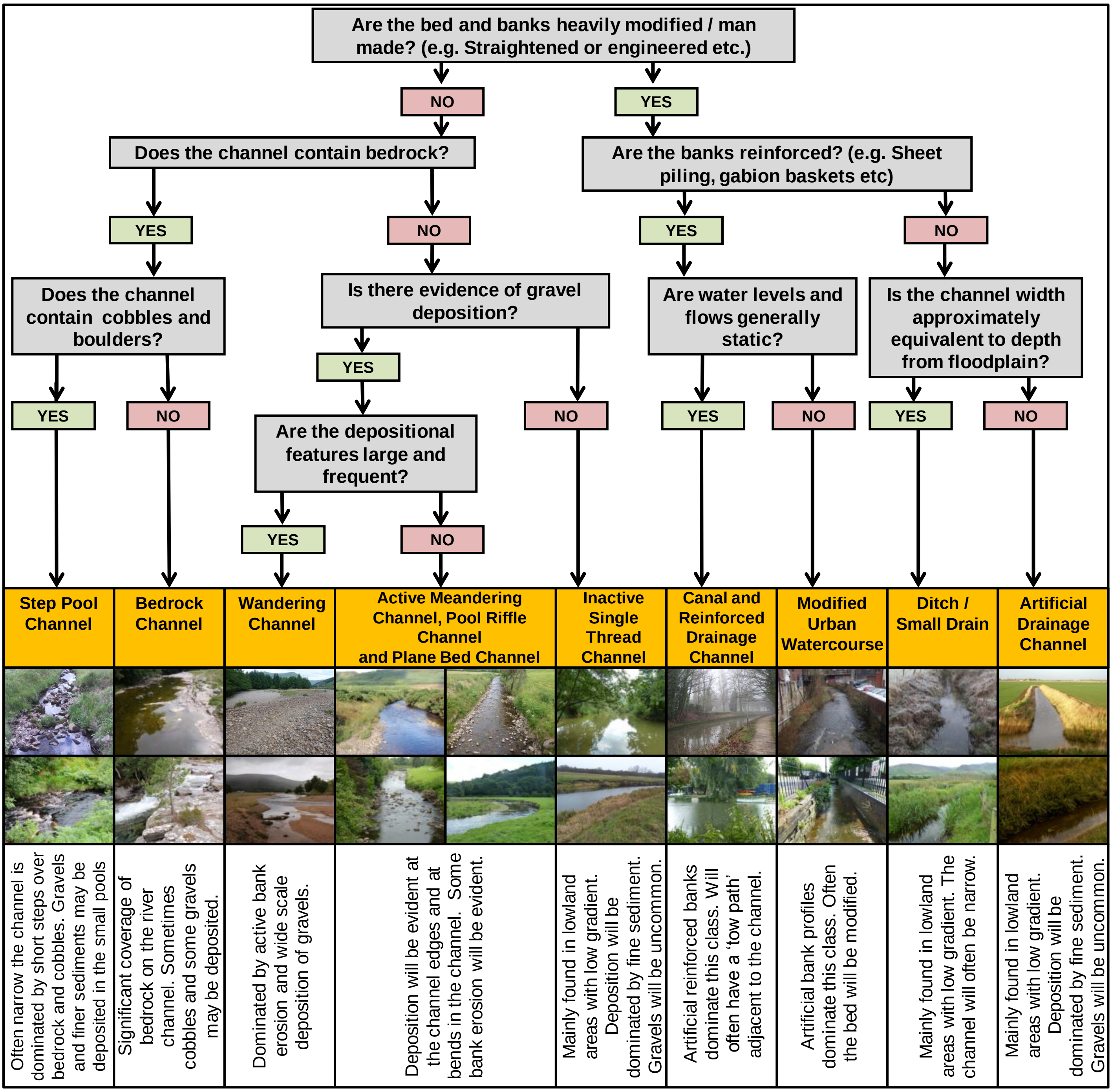


Figure 6.12 Flowchart for identifying geomorphic watercourse types

7. Techniques

7.1 Introduction

This chapter describes in detail the techniques available to manage aquatic and riparian vegetation. For each technique a brief summary of the method, best practice, timings and its benefits are provided, alongside a discussion of potential adverse impacts and other issues that require consideration such as licensing/ consenting requirements, health and safety issues, and waste disposal.

An indication of whether the technique provides short, medium or long-term control is also included. For the purposes of this guide:

- a **short-term** management technique is considered to provide effective management for one year or less
- a **medium-term** management technique provides effective management with no need for repeat operations for one to three years
- a **long-term** management technique will provide effective management for three or more years, although usually longer

An indication of the relative cost of the technique, either low (£), medium (££) or high (£££), is also provided. The number of variables being considered means that direct monetary comparison of the different techniques is not possible. Indicative, relative costs are provided, however, to allow watercourse managers to compare individual techniques.

The management techniques are described under four colour-coded categories:

- **Physical** – the active removal of plant material from a watercourse (section 7.3)
- **Chemical** – the application of herbicides and other substances to manage growth of plants (section 7.4)
- **Environmental** – the alteration of the conditions within or surrounding the watercourse to reduce or prevent plant growth (section 7.5)
- **Biological** – the use of biological control agents to control unwanted species or excessive plant growth (section 7.6)

A number of emerging **novel** techniques for vegetation management are also discussed (section 7.7).

In some situations an integrated approach to management using two or more techniques may be the most suitable approach. This is discussed in section 7.8.

7.2 Techniques considered

This guide considers the possible techniques to manage aquatic and riparian vegetation as detailed in Table 7.1. In some situations an integrated approach to management, using two or more techniques, may be the most suitable approach; this is discussed in more detail in section 7.8.

Table 7.1 Possible techniques for vegetation management

Category	Technique	Relevant section
Physical	Hand pulling	7.3.1
	Hand cutting	
	Hand raking	
	Mechanical harvesters	7.3.2
	Weed boats	
	Amphibious vehicles	
	De-weeding with a weed bucket	7.3.3
	De-weeding with a solid bucket	7.3.4
	Excavator and tractor mounted cutter/ flail	7.3.5
Chemical	Glyphosate-based herbicide	7.4.1
	Glyphosate-based herbicide with adjuvant	
	Barley straw	7.4.2
	Barley straw extract	
Environmental	Shading through tree/ hedgerow/ bankside planting	7.5.1
	Fencing to allow bankside vegetation growth for shading	
	Shading with native, broad-leaved floating species	
	Shading with opaque materials suspended over water	7.5.2
	Shading with benthic barriers	
	Dyes	7.5.3
	Water level manipulation	7.5.4
	Manipulation of flow characteristics	7.5.5
	Channel narrowing to increase velocity (two-stage channel)	
	Buffer strips	7.5.6
	Diffuse and point source pollution management	
	Nutrient-binding chemicals	
	Disturbance by boat traffic	7.5
Biological	Grazing of banks by cattle, sheep and horses	7.6.1
	Waterfowl	7.6.2
	Native fish species	7.6.3
	Invertebrates (for example, *Daphnia* spp., weevils)	7.6.4
Novel techniques	Hot foam	7.7.1
	Ultrasound	7.7.2
	Electromagnetic water treatment	7.7.3
	Suction harvesting	7.7.4
	Diver-operated suction harvesting	
	Hydro Venturi	
	Infrared	7.7.5

7.3 Physical techniques

Physical techniques involve actively removing plant material from a watercourse, and include a range of manual or mechanical activities. They are one of the most widespread means of managing aquatic and riparian vegetation both in the UK and elsewhere in the world.

Most native submerged, rooted floating-leaved and emergent plants are effectively controlled by physical techniques. Physical techniques tend to be less effective for free-floating species and filamentous green algae, and totally ineffective against unicellular green algae and cyanobacteria. Physical techniques are often not advisable for non-native invasive species and care is essential when managing these with physical techniques.

The most important benefit of physical techniques is that they have an **immediate impact**, with no delay between the operation being carried out and realisation of the effects.

Physical techniques rarely kill the plant species, with regrowth occurring immediately following management, within the same season or the following spring. Due to this, physical techniques usually only offer **short-term solutions** and it will be necessary to repeat management regularly, with the frequency depending on:

- the growth rate of the specific plant(s) of concern
- the function(s) of the watercourse

The **timing** of carrying out physical techniques is critical as stimulating regrowth may worsen the problem during the same growing season. If some plants are cut too early in a season, a second cut may be required if regrowth rates are rapid. The optimal timing for cutting will depend on the type of species and other considerations such as the presence of nesting birds and spawning fish. Figure 7.1 provides indicative timings for the optimal management of different groups of aquatic and riparian vegetation by physical techniques.

Free-floating species and algae are not included in Figure 7.1 as physical techniques are not very effective on these groups. Non-native invasive bankside species are also excluded as physical management of these should be undertaken with extreme care on a species-specific and site-by-site basis. Details of this in relation to each species are given in Chapter 5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Submerged					Physical management now will likely require repeat treatment					Die-back reduces need for management		
Rooted Floating Leaved					Physical management now will likely require repeat treatment					Die-back reduces need for management		
Tall Emergent					Physical management now will likely require repeat treatment					Standing dead material may require management		
Broad-leaved Emergent					Physical management now will likely require repeat treatment							
			Caution required with all physical techniques as birds nests may be present									
(dark shading)	Optimal period											
(light shading)	Sub-optimal period											

Figure 7.1 Indicative timings for physical management of species groups

Physical techniques are typically **non-selective** (particularly where large machinery is used, but less so with manual techniques) and can adversely impact non-target species.

They can also result in habitat disturbance and damage, for example, to:

- bankside habitats used by water voles *Arvicola amphibius* and small mammals
- spawning sites used by fish
- vegetation stands used by nesting birds

The timing of undertaking physical techniques in relation to **nesting birds** is a key consideration in planning management operations as the optimal period for managing most aquatic and riparian species starts in mid-July, when a number of birds are still likely to be nesting in and alongside watercourses. Any management activities carried out during the bird breeding season (March to September) carry the potential risk of damaging and destroying birds' nests. This risk can be reduced by:

- **Delaying the management operation** until later in the year. The peak bird breeding season is March to mid-July and after mid-July the likelihood of finding nests tends to decrease. Physical management operations before mid-July are discouraged. Until the end of September it is important to be alert to the potential presence of nests, with any nest locations avoided with an appropriate buffer zone (a minimum of 5 m either side is recommended).

- **Carrying out a survey for nests** and breeding bird activity along the watercourse to be affected immediately prior to the management being undertaken. The survey should be carried out by a competent person, with any nest locations marked and avoided with an appropriate buffer zone (a minimum of 5 m either side is recommended).

Other disadvantages of physical techniques are that they do not treat the underlying cause of the problem, such as nutrient enrichment, and in most cases do not remove the roots and rhizomes from which regrowth occurs. With some species, physical techniques can also facilitate their spread as fragments created during the operation are carried downstream to where new stands can establish; this is of particular concern when managing non-native invasive species. Many physical techniques can also be expensive due to the machinery and skilled labour they require.

Physical techniques also create **waste** which requires disposal, either by leaving it to decompose on the bank top away from the water or taking it away a permitted composting facility or an authorised landfill. Section 4.4.9 discusses waste management in further detail, including the need for waste exemptions and environmental permits.

Where physical techniques result in a build-up of plant matter and debris within the channel itself, it is important to harvest the material so that **deoxygenation** of the water does not occur as the material decays. If this is not done there is a risk of fish and invertebrates dying as a result of declining oxygen levels in the water.

As a general rule, physical techniques should not remove vegetation from the entire width of the channel, with **selective control** being practised. Figure 7.2 shows various approaches to how selective vegetation management can be undertaken.

Figure 7.2 Potential approaches to selective vegetation management

There are several advantages in doing this.

- Economic benefits can be achieved as the operation can be conducted more quickly with less material to cut, remove and dispose of.

- The impact on the environment is minimised as some habitat and cover is retained.
- Where plant material is retained along the toe of the banks it helps with bank stability and protects the banks from erosion.
- Partial cutting retains a variety of species at different life stages. Cutting the full width of the channel will stimulate regrowth which may result in extremely dense stands developing all at the same time, worsening problems.

7.3.1 Hand pulling, hand cutting and hand raking

Summary: Manual removal of plant material by hand (pulling) or using hand tools (cutting or raking). Generally only feasible on small localised patches.

Cost: £££ / £ (if volunteers are used)

Short-term option

These techniques actively remove plant material from a watercourse by hand or through the use of hand tools. Manual techniques such as hand pulling, cutting or raking were still used for management of watercourses in the UK up to the 1980s, but even by then their use was decreasing due to rising costs. Manual techniques are now used much less frequently.

Hand pulling does not involve any tools and can only successfully be used for shallow-rooted species, such as Himalayan balsam, and where soft silts are present, which allows them to be easily pulled up. Longer-term control can be achieved by hand pulling if the rhizomes are uprooted as well as the aboveground growth. The technique can be conducted from the bankside for tall emergent and other riparian species, or from within the channel or from a boat for other groups of species. Hand pulling of submerged species can be a very difficult and labour-intensive process, though it can be carried out by divers using snorkelling or scuba equipment when in deeper waters.

This technique is often used on floating pennywort, usually following implementation of another management technique, to ensure that all plant fragments are removed to prevent reinfestation. It is also frequently used as an approach to managing Himalayan balsam.

Hand cutting involves using a range of tools such as scythes, knives, sickles or machetes to control vegetation manually. It can be used on small, localised areas of problematic plants, but generally only where water levels are shallow and where the channel bed is solid to allow safe access and handling of tools. When working within the watercourse, hand cutting should be conducted in an upstream direction so that material is washed away from the work area, preventing entanglement with the vegetation that is being managed which can slow progress.

Following hand cutting of in-channel plants, it is necessary to remove the cut material to prevent it floating downstream and causing blockages or resulting in deoxygenation. This can be a time-consuming, difficult and costly exercise.

Hand raking is useful for removing aquatic plants, either following cutting operations, or when managing small patches of submerged species or filamentous green algae. A range of rakes are available to perform this work and allow material to be dragged out of the watercourse and onto the banks. This work is usually carried out from the banksides.

Benefits	Disadvantages
Impact is immediate.	Short-term option which leads to regrowth. Repeat treatment, often within the same season, will be required.
Use of volunteers can reduce costs.	Expensive when using a paid workforce.
Very selective and can target only the species of concern, particularly compared with other physical techniques.	Time-consuming and labour-intensive. Can generally only be used on short lengths of watercourse and localised areas.
Environmental impact is minimal. Manual techniques are useful for sensitive areas where mechanical or chemical techniques cannot be used.	Disposal of plant material needs to be considered. An application for exemptions/ permits from the Environment Agency/ Natural Resources Wales is necessary.
Skilled workforce is not required.	Some species can be poisonous to livestock and remain so following cutting.

The use of volunteers

If using volunteers to undertake vegetation management, it is essential to ensure all appropriate health and safety issues are considered, and risk assessments, method statements and insurances are in place before work begins. Volunteers must be adequately trained and provided with all necessary tools, resources and PPE necessary. Those supervising volunteer workforces should also be sufficiently trained to do so.

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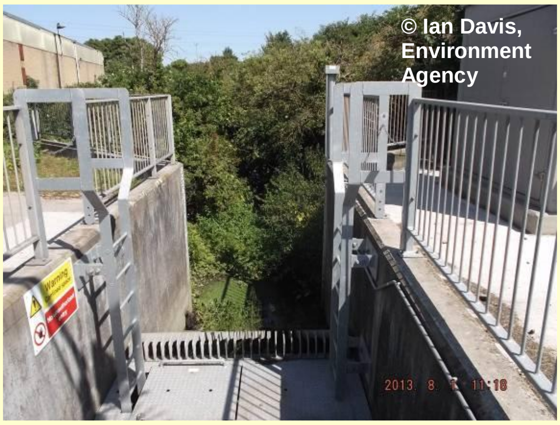
Key considerations

- **Cost –** manual techniques are likely to be expensive, unless volunteers are used.
- **Health and safety** – all appropriate risk assessments, method statements and insurances must be in place and all operatives/ volunteers must be provided with appropriate PPE and tools, particularly when working with toxic plants or sharp tools.
- **Waste disposal** – applications must be made for the appropriate exemptions/ permits for waste disposal from the Environment Agency/ Natural Resources Wales.

Example: Buzzards Mouth Sewer, Barking, London

Buzzards Mouth Sewer, which flows through Creekmouth near Barking in London, drains a dense urban area at high flood risk. Over 4,000 new houses are also being constructed in the area. The watercourse has a very low gradient and is tide-locked by the Thames for around 75% of each tide cycle, making drainage critical at low tide.

The channel has not been managed for several years due to access restrictions and hostility from local site owners. Vegetation growth has now become extremely dense, with significant stands of tall emergent common reed *Phragmites australis* and areas where scrub growth is impenetrable. Due to these access restrictions and the dense vegetation, management will be by hand cutting with power tools.



7.3.2 Mechanical harvesters, weed boats and amphibious vehicles

Summary: Mechanical management of vegetation using a vehicle working from within the channel itself. A range of vehicles are available for performing this work.

Cost: £ / ££ (depending on type of vehicle used)

Short-term option

These mechanical techniques require specialist machinery that can work from within the channel such as mechanical harvesters, weed boats and amphibious vehicles. The machines are capable of being fitted with a range of mechanical and hydraulic attachments to carry out specific management tasks and for the management of different groups of species.

In general, attachments for vegetation management can include:

- **Cutter bars** – these can be either a unit on the front of the vehicle (for example, a T-front cutterbar) or a side cutterbar often used to mow embankments
- **Weed cutting baskets and cutting knives** – a perforated bucket or cutter with reciprocating cutting blades to cut vegetation
- **Trailing knives** - a chain with a V-shaped blade that is pulled over the watercourse bed with a jolting movement to cut and pull out vegetation (This type of attachment can adversely impact on the bed of a watercourse and mobilise significant quantities of silt.)
- **Push or collecting frames/ rakes** – an attachment to collect cut vegetation and floating debris and deposit it at the side of the watercourse

The attachments can either be in fixed positions or on an arm which allows the head to work up and down the banks and reach other locations.

Weed boats can be fitted with a wide range of attachments as detailed above to manage submerged, floating and emergent vegetation.

Mechanical harvesters are boats that, as well as being fitted with equipment to cut the vegetation, are also able to collect and store cut material on board for disposal once the operation is complete and the machine returns to land. Mechanical harvesters are often the best physical technique for managing free-floating species such as duckweeds, as the plants are collected and removed from the watercourse, which other physical techniques do not.

Amphibious vehicles have the benefit of being able to work in much shallower waters than required for weed boats or mechanical harvesters. They are either wheeled or tracked machines, and can generally access watercourses much more easily and in more locations than other types of in-channel vehicle.

As they are tracked or wheeled, amphibious vehicles can damage the bottom of watercourses and should be used with extreme care in watercourses sensitive to sediment mobilisation, and also where important features such as spawning gravels are present.

Working with amphibious vehicles should be avoided during fish spawning seasons (that is, generally November to March for salmon and trout and April to June for coarse fish).

These vehicles cannot be used in narrow watercourses, and in the case of weed boats and mechanical harvesters, watercourses with shallow water (approximately 0.4 m).

These in-channel vehicles can be very effective at managing submerged, rooted floating-leaved, tall emergent and broad-leaved emergent species and also stoneworts (charophytes). With the exception of mechanical harvesters, they are generally ineffective on free-floating species and filamentous green algae.

Extreme care should be taken when managing non-native invasive species with these in-channel vehicles as many of the attachments result in fragmentation of the plant, which can result in their reestablishment and spread downstream.

STOP THE SPREAD
INVASIVE AQUATIC SPECIES
CHECK-CLEAN-DRY

Best practice working methods

When carrying out management using these in-channel vehicles, vegetation should not be removed from the entire channel width. Management should be conducted selectively, with some vegetation retained for biodiversity and for bank stabilisation purposes.

There are many approaches to how and to what extent vegetation may be managed within a channel to bring about both flood risk management and biodiversity benefits, amongst others. Further information can be found in:

- Environment Agency FCRM Asset Management Maintenance Standards
- *The Drainage Channel Biodiversity Manual* (Buisson et al. 2008)

When working within flowing watercourses, the vegetation should be cut in an upstream direction. This makes the operation easier, and allows plant fragments and associated invertebrates to drift downstream and recolonise the watercourse. In still and very slow-flowing water bodies, in-channel vehicles can operate in either direction.

In large, wide channels, the vehicle may need to pass up and down the channel more than once to ensure the desired quantity of vegetation is cut. In some watercourses, to increase the diversity of flow conditions and habitats within the channel, a meandering channel could be cut through the vegetation, though this is not as hydraulically efficient as a straight channel.

The **timing** of management is also important, as generally management is only required once significant growth has occurred, usually by late spring or early summer, although this varies depending on site conditions and the species present. Management conducted during the spring and summer carries a significant risk of damaging and destroying birds' nests in and alongside watercourses and is discouraged until mid-July. After mid-July and until the end of September, it is necessary to be alert to the potential presence of nests in and alongside watercourses, or to carry out a survey immediately before the works. If found, a nest should be safeguarded with an appropriate buffer zone (a minimum of 5 m either side is recommended) to prevent damage and/ or destruction.

Cutting before mid to late summer may require a second cut to be made later in the autumn as regrowth is stimulated. Cutting in mid to late summer or later can be more difficult and time-consuming as there is usually a greater density of vegetation.

The function(s) of the watercourse needs to be assessed to determine whether two or more regular cuts are needed during the year which remove less plant material, or one later operation which removes significant quantities of plant material. Regular cutting operations are generally only implemented in exceptional circumstances, such as in high flood risk locations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Submerged					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Rooted Floating Leaved					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Tall Emergent					Cutting now will likely require repeat cuts					Standing dead material may require management		
Broad-leaved Emergent					Cutting now will likely require repeat cuts							
			Caution required with all physical techniques as birds nests may be present									
(dark shading)	Optimal period											
(light shading)	Sub-optimal period											

For most mechanical techniques, it is the removal of the vegetation from the water which takes the most time and incurs the most cost; mechanical harvesters can help by reducing the time and costs associated with collecting material. It is best practice to remove cut material from the watercourse to prevent deoxygenation as it decomposes and can also block screens, culverts and other structures. With weed boats and amphibious vehicles it may also be possible to allow cut material to float downstream to a boom, weed screen or specified collection point enabling for easier collection. When collected in one location, off-site disposal may be required which will increase costs.

It is also best practice to place the cut material on the bank top, either to decompose entirely or to allow it to drain prior to off-site disposal. This also allows any invertebrates that have been removed incidentally with the plant material to recolonise the watercourse. Section 4.4.9 discusses waste management in further detail, including the need for waste exemptions and environmental permits.

Benefits	Disadvantages
Impact is immediate.	Short-term option which leads to regrowth. Repeat treatment, often within the same season, will be required.
Generally rapid and cost-effective, particularly on large watercourses.	Non-selective and destructive techniques that impact on non-target species, including fish and invertebrates.
Costs may be offset by finding a use for the cut vegetation (for example, as livestock fodder).	Cut plant material requires collection from the water (not with mechanical harvesters) and appropriate disposal. It will be necessary to apply for appropriate exemptions/ permits from the Environment Agency/ Natural Resources Wales.
	Some species can be poisonous to livestock and remain so following cutting.
	Fragments are created from which plants can re-establish and potentially spread downstream.
	Machines are often only used seasonally and remain unused for significant portions of a year.
	A suitable and safe launching site is required.
	Skilled and competent staff are required to operate these vehicles; specialist contractors may need to be appointed.

Key considerations

- **Waste disposal** – applications must be made for the appropriate exemptions/ permits for waste disposal from the Environment Agency/ Natural Resources Wales.
- **Timing** – the work must be scheduled carefully, taking into account nesting birds and other environmental constraints.
- **Access** – a safe and suitable launching site needs to be found.
- **Size of watercourse** – in-channel vehicles are only suitable for use on larger watercourses (approximately 4 m wide and 0.4 m deep).
- **Selective control** – the aim should be to retain as much in-channel vegetation as possible while ensuring the function(s) of the watercourse is maintained.

7.3.3 De-weeding with a weed bucket

Summary: Mechanical management of vegetation using an excavator or tractor fitted with a weed cutting bucket. Work is undertaken from the banksides, not within the channel.

Cost: ££

Short-term option

In most cases de-weeding with a weed bucket is conducted using an excavator fitted with a specialist weed cutting bucket or basket. In some cases they can be fitted to tractors. Weed cutting buckets/ baskets are available in a variety of sizes and one appropriate for the watercourse size being managed should be selected.

Weed cutting buckets/ baskets generally have a powered cutter bar on the front which has reciprocating blades to cut through vegetation including tall emergent, submerged, rooted floating-leaved and broad-leaved emergent species. They are also usually perforated or formed of a lattice of bars to allow water and silts collected with the vegetation to drain back into the channel.

Extreme care should be taken when managing non-native invasive species using this technique as the cutting buckets/ baskets result in fragmentation of the plant, which for many non-native invasive species can result in their re-establishment and spread downstream.

Best practice working methods

When undertaking management using weed cutting buckets/ baskets, vegetation should not be removed from the entire channel width. Selective management should be carried out with some vegetation retained for biodiversity and for bank stabilisation purposes.

There are many approaches to how and to what extent vegetation can be managed within a channel to bring about both flood risk management and biodiversity benefits, amongst others. Further information can be found in:

- Environment Agency FCRM Asset Management Maintenance Standards
- *The Drainage Channel Biodiversity Manual* (Buisson et al*.* 2008)

When working within flowing watercourses, vegetation should be cut in an upstream direction as this makes the operation easier, and allows plant fragments and associated invertebrates to drift downstream and recolonise the watercourse. In still and very slow-flowing water bodies, in-channel vehicles can operate in either direction.

To achieve longer-term control, the weed cutting bucket can be inserted more deeply into the silts of the watercourse so that some rhizome and root material is removed to reduce regrowth and the frequency of management required. This is not possible where harder bed substrates are present as the cutting blades may be damaged and the impacts of silt mobilisation caused by this need to be considered.

Work should be conducted from one bank only, with the other left unaffected, so that disturbance is limited.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The **timing** of management is also critical. Generally management is only required once significant growth has occurred, usually by late spring or early summer, though this varies depending on site conditions and the species.

Management conducted in the spring and summer carries a significant risk of damaging and destroying birds' nests in and alongside watercourses, and is discouraged until mid-July at the earliest. After mid-July until the end of September, it is necessary to be alert to the potential presence of nests in and alongside watercourses. If found, a nest should be safeguarded with an appropriate buffer zone (a minimum of 5 m either side is recommended) to prevent damage and destruction.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Submerged					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Rooted Floating Leaved					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Tall Emergent					Cutting now will likely require repeat cuts					Standing dead material may require management		
Broad-leaved Emergent					Cutting now will likely require repeat cuts							
			Caution required with all physical techniques as birds nests may be present									
(dark shading)	Optimal period											
(light shading)	Sub-optimal period											

Cutting before mid to late summer may require a second cut to be made later in the autumn as regrowth is stimulated. Cutting in mid to late summer or later can be more difficult and time-consuming as there is usually a greater density of vegetation to be cut.

The function(s) of the watercourse needs to be assessed to determine whether two or more regular cuts are needed during the year which remove less plant material, or one later operation which removes significant quantities of plant material. Regular cutting operations are generally only implemented in exceptional circumstances such as in high flood risk locations.

Disposal of cut material needs to be considered carefully. In most cases the cut material can be deposited on the bank top.

Exemptions can be registered with the Environment Agency/ Natural Resources Wales that permit silt and plant material from watercourses to be deposited on the banks of the watercourse it was removed from as long as it can be deposited on that land by mechanical means in one operation.

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This should always be done above the flood level and not on the slope of the bank where it may slide back into the watercourse, potentially causing issues with deoxygenation and blockages.

Deposition of cut material on the bank top is unlikely to be suitable in all situations, for example in urban areas or where recreational use is high. Costly off-site disposal may be needed in some cases with appropriate permits required from the Environment Agency/ Natural Resources Wales. Section 4.4.9 discusses waste management in further detail, including the need for waste exemptions and environmental permits.

Cut material may also contain invertebrates and so disposal on the bank top allows some to escape back to the water. Any fish removed from the watercourse in the weed cutting bucket should be returned to the watercourse wherever possible. Where large numbers of fish are being removed, an additional person on the bank can be useful to return fish, or the bucket can be kept in the water at the end of each cut for a few seconds to allow any fish to escape.

Benefits	**Disadvantages**
Impact is immediate.	Short-term option which leads to regrowth. Repeat treatment, often within the same season, will be required.
Relatively cost-effective and rapid method of managing long lengths of watercourse.	Non-selective and destructive technique that has impacts on non-target species, including fish and invertebrates which can be removed by the buckets – though this technique is generally more selective than in-channel vehicles, as sections of vegetation can be more easily retained.
Can be used in relatively narrow watercourses (unlike weed boats and other in-channel vehicles).	Fragments are created from which plants can re-establish and spread downstream.
Weed cutting buckets capture plant material as they operate, so there is no	It is necessary to apply for appropriate waste exemptions/ permits from the Environment Agency/ Natural Resources

Benefits	Disadvantages
requirement to then collect arisings.	Wales.
	Machine access is required along the full bank top, which may be restricted in some places. Moving around obstructions can increase costs.
	In narrow watercourses (<2 m wide), weed cutting buckets can damage the toe of the banks which can lead to undercutting and bank slippages. Damage may also occur to bankside habitats, potentially including water vole *Arvicola amphibius* burrows.
	Significant quantities of silt can be mobilised.
	Reciprocating-blade cutter bars are prone to jamming with dense vegetation (for example, reedmace *Typha latifolia*) and damage from stones and other debris on the watercourse bed. Maintenance costs can therefore be high.
	Skilled and competent staff will be required to operate these vehicles, or specialist contractors will need to be appointed.
	Some species can be poisonous to livestock, and remain so following cutting.

Key considerations

- **Waste disposal** – applications should be made for the appropriate exemptions/ permits for waste disposal from the Environment Agency/ Natural Resources Wales.
- **Timing** – the work should be scheduled carefully, taking into account nesting birds and other environmental constraints.
- **Access** – machine access will be required along the bank top for the full length of the watercourse.
- **Size of watercourse** – in narrow watercourses (<2 m width) care needs to be taken or alternative management techniques selected to avoid damage to the toe of the banks.
- **Selective control** – the aim should be to retain as much in-channel vegetation as possible while ensuring the function(s) of the watercourse is maintained.

7.3.4 De-weeding with a solid bucket

Summary: Mechanical management of vegetation using an excavator or tractor fitted with a solid bucket. Work is undertaken from the banksides, not within the channel.

Cost: £££

Short–medium term option

De-weeding with a solid bucket is accomplished using machinery fitted with solid buckets and is the most invasive physical technique available. However, this method of removing vegetation and sediment is the most effective physical technique in terms of the length of effect as the root and rhizome material is also removed.

De-weeding with a solid bucket is not often carried out for the sole purpose of vegetation management as it is expensive and environmentally damaging. Removal of vegetation is often the incidental result of channel management operations such as de-silting or dredging, which are conducted with a solid bucket.

De-weeding with a solid bucket is a very environmentally damaging technique to manage vegetation in watercourses. This option should be selected with extreme caution for the following reasons.

- It is non-selective and can adversely impact on a range of non-target species.
- It can result in damage to aquatic and bankside habitats, potentially those of protected species such as water vole *Arvicola amphibius*.
- It also mobilises significant quantities of silt.

Best practice working methods

Management operations should not remove silt and vegetation from the entire channel width. Some should always be retained to maintain biodiversity and for bank stabilisation purposes.

Disposal of the cut material needs to be considered carefully. In most cases the cut material can be deposited on the bank tops. Exemptions can be registered with the Environment Agency/ Natural Resources Wales that permit silt and plant material from watercourses to be deposited on the banks of the waters it was removed from, or on land adjoining the water from which it was removed from, as long as it can be deposited on that land by mechanical means in one operation. This should always be done above the flood level and not on the slope of the bank where it may slide back into the watercourse, potentially causing issues with deoxygenation.

Deposition of material removed on the bank top is unlikely to be suitable in all situations, for example, in urban areas or areas of recreational use. Costly off-site disposal may be required in these cases and it will be necessary to apply for appropriate permits from the Environment Agency/ Natural Resources Wales. Section 4.4.9 discusses waste management in further detail, including the need for waste exemptions and environmental permits.

Removed material may also contain invertebrates and so disposal on the bank top allows some to escape back to the water. Any fish removed from the watercourse in the bucket should be returned to the watercourse wherever possible. Where large numbers of fish are being removed, a person on the bank can be used to return fish to the water, or the bucket can be kept in the water at the end of each cut for a few seconds to allow any fish to escape.

The **timing** of management can also be important. Generally management for vegetation is only required once significant growth has occurred, usually by late spring or early summer, although this varies depending on site conditions and the species.

Management conducted during the spring and summer carries a significant risk of damaging and destroying birds' nests in and alongside watercourses and is discouraged until mid-July at the earliest. After mid-July and until the end of September, it is necessary to be alert to the potential presence of nests in and alongside watercourses. If found, a nest should be safeguarded with an appropriate buffer zone (a minimum of 5 m either side is recommended) to prevent damage and destruction.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Submerged					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Rooted Floating Leaved					Cutting now will likely require repeat cuts					Die-back reduces need for management		
Tall Emergent					Cutting now will likely require repeat cuts					Standing dead material may require management		
Broad-leaved Emergent					Cutting now will likely require repeat cuts							
			Caution required with all physical techniques as birds nests may be present									
	Optimal period											
	Sub-optimal period											

When working within flowing watercourses, the work should be conducted in an upstream direction as this makes the operation easier, and allows plant fragments and associated invertebrates to drift away downstream and recolonise.

Extreme care should be when managing non-native invasive species using this technique as it can result in fragmentation, which for many non-native invasive species can result in their re-establishment and spread downstream.

STOP THE SPREAD INVASIVE AQUATIC SPECIES CHECK-CLEAN-DRY

Benefits	Disadvantages
Impact is immediate.	Very expensive and labour intensive.
Effect is longer-term in comparison with other physical techniques as roots and rhizome material is removed.	Non-selective and very destructive technique that adversely impacts on non-target species including fish, benthic organisms and invertebrates.
Can be combined with other channel management operations such as reprofiling and de-silting.	Significant quantities of silt can be mobilised, which may contain nutrients or contaminated material which are then released into the water.
	Solid buckets, particularly in narrow watercourses (<2 m wide) can damage the toe of the banks, which can lead to undercutting and bank slippage. Damage may also occur to bankside habitats, potentially including water vole *Arvicola amphibius* burrows.
	Fragments are created from which plants can re-establish and spread downstream.
	Machine access is required along the full bank top, which may be restricted in some places. Moving around obstructions can increase costs.
	Waste generated could be significant and it will require appropriate disposal. It is necessary to apply for appropriate waste exemptions/ permits from the Environment Agency/ Natural Resources Wales.
	Skilled and competent staff will be required to operate these vehicles, or specialist contractors appointed.

Key considerations

- **Environmental impact** – de-weeding with a solid bucket is a very environmentally damaging technique which should be selected with caution.
- **Pre-works surveys** – prior to any de-weeding with a solid bucket, a survey is recommended to determine what environmental impacts may arise and what measures are needed to minimise these impacts.
- **Consent** – consent will be needed from the Environment Agency/ Natural Resources Wales if the watercourse is Main River, or the IDB/ LLFA if it is an Ordinary Watercourse.
- **Waste disposal** – applications must be made for appropriate exemptions/ permits for waste disposal from the Environment Agency/ Natural Resources Wales.
- **Timing** – the work should be scheduled carefully, taking into account nesting birds and other environmental constraints.
- **Selective control** – the aim should be to retain as much in-channel vegetation as possible while ensuring the function(s) of the watercourse is maintained.
- **Access** – machine access will be required along the bank top for the full length of the watercourse.
- **Size of watercourse** – in narrow watercourses (<2 m width) care is needed, or alternative techniques selected, to avoid damage to the toe of the banks.

7.3.5 Excavator and tractor mounted cutter/ flail

Summary: Mechanical cutting of vegetation on the banksides and in the riparian zone using a specialist tool – usually fitted to an excavator or tractor. Work is performed from the banksides.

Cost: ££

Short-term option

This technique involves using a flail mower or cutter, usually mounted on a tractor or wheeled excavator. It is often used in conjunction with other physical techniques when maintaining both the in-channel and bankside/ riparian areas of a watercourse.

Its primary purpose is to remove bankside vegetation and vegetation from within the riparian zone which can impede flows. It is often carried out prior to de-weeding to enable the operative to be able to see the channel more clearly. It is generally used for grasses and light vegetation, but hedgerows can also be managed using this machinery. More heavy duty cutters and mowers can be purchased for the management of scrubby vegetation.

Best practice working methods

Only one bank should be cut so that the opposite bank is retained in a vegetated state, providing cover and a food source for a range of species. Where possible the cut bank should be alternated to minimise disturbance and to prevent woody vegetation becoming dominant – but only when the desired vegetation is not scrub cover. In some cases cutting only half a bank may be possible.

The **timing** of the cut is also important, as generally management is only required once significant growth has occurred, usually by late spring or early summer, although this varies depending on site conditions and the species present. At this time there is a significant risk to birds' nests within bankside and emergent vegetation and **it should not be conducted before mid-July at the earliest**.

Even undertaking operations after mid-July (usually until the end of September) may impact on birds' nests. It is necessary to be alert to the potential of finding nests within stands of vegetation; alternatively a survey should be carried out before work begins. Where nests are found, a buffer zone of unmanaged vegetation should be left around them (a minimum of 5 m either side is recommended).


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Before implementing management, other impacts of cutting earlier in the season should also be considered including removing cover for fauna and a nectar source for invertebrates.

Cutting before mid to late summer may require a second cut to be made later in the autumn as regrowth will be stimulated. In mid to late summer or later, cutting will be more difficult and time-consuming as there will be a greater density of vegetation to cut. The most appropriate approach needs to be selected depending on the function(s) of the watercourse and the species.

The frequency of bankside cutting will depend on the objectives for the watercourse being managed. For example, where the aim is to promote growth of in-channel submerged and floating vegetation, shading from bankside vegetation should be minimised by cutting in late winter or early spring (that is, before March) to delay spring regrowth in favour of in-channel species. Where the aim is to promote the diversity of the bankside grasslands themselves they should be cut annually in late winter–early spring with all arisings removed, or twice yearly in autumn and then again late winter–early spring.

To promote the growth of scrub or extensive reed beds, the frequency of cutting should be reduced to once every 5–10 years.

Extreme care should be taken when managing vegetation using a flail mower or cutter as it can result in fragmentation, which for many non-native invasive species can result in their re-establishment and spread.

STOP THE SPREAD
INVASIVE AQUATIC SPECIES
CHECK-CLEAN-DRY

New developments

Some machines can be fitted with a rake or conveyor to remove grass cuttings from the slope of the bank to prevent them entering the watercourse or remaining on the banksides. When grass cuttings are left in situ, they input nutrients to the habitat as they decompose. This allows a few nutrient-demanding species to become dominant at the expense of a more species-rich sward.


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New mowing machines are also becoming available which can manage vegetation similar to that of an excavator or tractor mounted flail/ cutter. These include robotic mowers which are unmanned and can be used in situations where bank stability or health and safety issues prevent use of a manned machine, and also ‘spider’ mowers that operate within the channel between the banks.

Benefits	Disadvantages
Impact is immediate.	Cut material usually remains in situ, possibly smothering other vegetation and leading to nutrient enrichment and potentially reduced species-richness.
Machinery is often multi-purpose and can be used for operations other than watercourse maintenance.	Cut material can fall, be blown or washed into the watercourse which can potentially cause blockages, look unsightly or, in extreme circumstances, cause deoxygenation.
Relatively cost-effective technique for managing the banksides and riparian zones of long lengths of watercourse.	Technique cannot be used on in-channel vegetation, only that within the riparian zone above the water level, and on the banksides.
	Skilled and competent staff will be required to operate these vehicles, or specialist contractors will need to be appointed.
	Appropriate permits/ exemptions will be required from the Environment Agency/ Natural Resources Wales for disposal of cut material, even when left in situ.

Key considerations

- **Timing –** the work should be scheduled carefully, taking into account nesting birds and other environmental constraints.
- **Selective control –** the extent of cutting/mowing should be planned carefully, with one-bank, partial and rotational operations being carried out where possible.
- **Access –** machine access will be required along the bank top for the full length of the watercourse.
- **Waste disposal –** applications must be made for appropriate exemptions/ permits for waste disposal from the Environment Agency/ Natural Resources Wales.

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7.4 Chemical techniques

This section is concerned with the management of aquatic and riparian plants using chemicals, including herbicides.

Herbicides are chemicals used to control unwanted plants. They can be selective and impact on only a limited range of plants, or they can be non-selective impacting on a wide range of species. They can either be contact herbicides which affect only the part of the plant that is touched, or they can be absorbed into the plant and translocated elsewhere to impact on a vital process, killing the plant. They can also be persistent and remain in soil, water or sediment for a considerable period of time, or non-persistent and have no activity in soil, sediment or water.


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Herbicides have long been available as a technique for aquatic and riparian plant management. Over recent years their use has declined primarily since the implementation of the EU Plant Protection Products Directive and various national regulations made under the directive; this has changed the legislative framework in which herbicide application can occur (see Appendix A for a review of the current legislative framework).

In 1993 eight active herbicide ingredients were approved for use in or near water. By 1999 this had reduced to five and in 2013 only two are approved. Approval for one of these two, 2,4-D amine, will be revoked and it cannot be used after 30 June 2018. As this active ingredient is in the process of being withdrawn, herbicides containing this active ingredient will not be considered further within this guidance. Only herbicides containing the active ingredient glyphosate are therefore considered as a feasible management option (see section 7.4.1).

The perceived impact of herbicide use on the aquatic and riparian environment is one of the main factors that has led to a decline in their use over recent years, with physical techniques often used in preference. However, herbicides can be an effective management technique for aquatic and riparian vegetation as they can be applied quickly, safely and relatively cheaply in comparison with physical techniques and are less intrusive.

Other substances, including the use of barley straw and barley straw extract, can also be used to chemically control some groups of aquatic and riparian vegetation (that is, algae) (see section 7.4.2).

At the RSPB's Old Hall Marshes Reserve in Essex, a highly unusual chemical treatment was trialled to control an infestation of Australian swamp stonecrop *Crassula helmsii*. This species is intolerant of salt and, at this coastal reserve, an area was flooded with seawater for 12 months and the plant was eradicated. The RSPB is now trialling this technique at a second site at the Conwy Reserve in North Wales. However, altering the chemistry of freshwaters through the introduction of salt or brackish water potentially has major environmental impacts and significant effects on non-target species. Its use as a general management technique for aquatic and riparian vegetation within inland watercourses is discouraged and it is not discussed further in this guide.

7.4.1 Glyphosate-based herbicide and use of adjuvants

Summary: Control of problematic stands of emergent and floating vegetation through the application of chemicals containing the active herbicide ingredient glyphosate. Special additives, adjuvants, can also be used to increase their effectiveness.

Cost: £

Medium-term option

Glyphosate is used in non-selective herbicides, which are absorbed by the foliage and rapidly translocated through the plant. As these herbicides act by contacting the foliage and then being absorbed by the plant, glyphosate-based herbicides cannot be used on submerged species and algae growing beneath the water surface. However, they can be used on species that have emergent or floating leaves for some of their life-cycle.

Glyphosate rapidly degrades in soils and water and it does not persist in the environment. It is cleared for safe use in or near watercourses and is considered by the World Health Organization not to represent a hazard to human health under usual conditions.

Adverse impacts can arise if used incorrectly or misused. For example, herbicide applications that kill plants very quickly can cause deoxygenation of the water as decomposition occurs, possibly resulting in the death of fish and invertebrates.

As a non-selective herbicide, glyphosate should not be used in locations where protected or rare plant species are present.

A major consideration when using herbicides is recognising that there is a lag time between application of the chemical and realisation of the hydraulic benefits, as plants take some time to die back, or the reduction in regrowth may not materialise until the following growing season. Consequently, herbicides are not a feasible option where a rapid solution to a critical flood risk issue is required.

Glyphosate-based herbicides generally have a longer-term impact on vegetation than physical techniques, with regrowth often reduced for two or three subsequent growing seasons, depending on the species. This reduces the frequency of management required in a watercourse and associated habitat disturbance. However, the impact of longer-lasting plant management needs to be considered.

Agreement to use herbicides in or near water

All management of aquatic and riparian vegetation using herbicides requires agreement from the Environment Agency/ Natural Resources Wales.

To obtain agreement, a range of information will need to be supplied including details of the site, the problem species, any nature conservation sites, downstream users and fish presence, the herbicide to be used and how it will be applied.

Guidance and the application forms to apply for agreement are available from:

- Application to use herbicides in or near water (https://www.gov.uk/government/publications/application-to-use-herbicides-in-or-near-water)
- Natural Resources Wales – using herbicides (http://naturalresourceswales.gov.uk/apply-buy-report/apply-buy-grid/water/using-herbicides/?lang=en)

Anyone who uses herbicides in or near water must have the necessary skills, knowledge and qualifications. They must hold a relevant National Proficiency Test Certificate (NPTC) of competence, which must be supplied with the application. The NPTC must be for applying herbicides in or near water.

Method of application

Glyphosate-based herbicides can be a useful and effective method of managing aquatic and riparian vegetation, but if used incorrectly they can be expensive, ineffective and damaging to the environment. The method of application is critical.

A range of equipment is available to apply glyphosate-based herbicides, either hand-held or vehicle-mounted.

Knapsack sprayers, hand-held weed wipers and coarse droplet applicators (CDAs) are suitable for applying herbicide over relatively small areas or for spot treatment. They can be used from a boat or from the bank.

Hand-held equipment used from the bankside can have difficulties in reaching some areas, particularly on wide watercourses, but long-lance sprayers (which can reach up to 5 m) are available.

Boat-mounted, tractor-mounted or all-terrain vehicle (ATV) mounted equipment is also available. ATV or tractor-mounted equipment allows coverage of larger areas, although access will be required along the bankside and a long enough boom will be required to reach the channel.

Boat-mounted equipment causes issues as the speed of the boat alters dose rates and the wash of the boat can submerge treated floating or emergent leaves, washing off or preventing contact with the herbicide. When using a boat-mounted sprayer, use the slowest speed setting to cause minimum disturbance.

In selecting the method of application, it is necessary to consider:

- size of the watercourse
- access issues
- extent and location of the vegetation requiring treatment

All herbicides must be used under strict control and in accordance with the instructions printed on the product label. All products used in or near water must be appropriately labelled for this use. This label will provide details on the dose rate, timing of application and susceptible species.

A number of glyphosate-based herbicide products are available for use in or near water. The product selected should have minimal environmental impacts and low ecotoxicity levels to ensure no adverse impacts on aquatic habitats and species. These products are often labelled as 'biactive' formulations. The Material Safety Data Sheets for individual products, which detail information on ecotoxicity, can be found on the manufacturers' and/ or suppliers' websites.

The Control of Substances Hazardous to Health (COSHH) Regulations 2002 require that the formulation with the lowest possible impact on the environment and human user is used. A COSHH risk assessment should detail this.

In general, the following principles should be followed when applying herbicides:

- Avoid spraying immediately after rain when the plant leaves are wet.
- Avoid spraying when wind speed exceeds a gentle breeze (10 kph).
- Avoid spraying in very calm conditions when convection currents may lift droplets and carry them elsewhere.
- Undertake spraying in an upstream direction.
- Avoid trampling or breaking vegetation as this reduces the effectiveness of the chemical.
- Avoid spraying when water levels are high as wash-off may occur.
- Do not over-spray leaves as excess herbicide will run-off the leaf.
- Use correct nozzle sizes to give the required volume rate at the recommended pressure.
- Use low pressure nozzles with a defined swath to minimise the risk of drift and impacts on non-target species.
- Calibrate spraying equipment before each application and thoroughly check and clean all equipment after use.

Adjuvants

Adjuvants are substances, other than water, added to enhance the effectiveness of a herbicide, for example by helping the herbicide to 'stick' to a leaf for longer giving more opportunity for it to be absorbed.

This is particularly important for species with waxy leaves or those which readily shed water (that is, hydrophobic leaves), such as floating pennywort or parrot's-feather.

Additionally, for species such as floating pennywort which rapidly intake and excrete herbicides through their root systems, adjuvants can help to slow down the intake of the herbicide by slowly releasing the chemical, allowing it more time to act on the plant.

Adjuvants that are most frequently used with glyphosate-based herbicides are typically vegetable oil or soya-based products that act as emusifiers or sponges enabling the herbicide to remain on the leaf surface for a longer period.

Always use adjuvants with the following species to ensure effectiveness

- Parrot's-feather *Myriophyllum aquaticum*
- Broad-leaved pondweed *Potamogeton natans*
- Fringed water-lily *Nymphoides peltata*
- Floating pennywort *Hydrocotyle ranunculoides*
- Water-primroses *Ludwigia spp.*
- Australian swamp stonecrop *Crassula helmsii*

They can also be used with other species to increase effectiveness of the treatment.

Timing

As a general rule, glyphosate-based herbicides must be applied to green, actively growing plants, and not after they have started to die back.

The optimal period to apply glyphosate-based herbicides varies with the species as shown in Figure 7.3. Details are also provided in relation to each species in Chapter 5.

The recommended treatment period for the majority of species is mid to late summer. When sprayed at this time, the plants generally appear to die back at the same rate as the unsprayed plants; however, the sprayed plants will not regrow back the following spring. For some species, growth in subsequent seasons is also much reduced.

For some species, including reed sweet-grass *Glyceria maxima* and tall sedges *Carex* spp., treatment earlier in the summer, during May and June, can also have some benefits by reducing growth within the same growing season. This can help to keep channels more open during the late summer and autumn, which can be of benefit by reducing the risk of summer flooding and keeping channels clear for other purposes, such as irrigation.

Group	Common name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Submerged	Parrot's-feather (emergent parts only)												
Free-floating	Duckweeds (excluding least duckweed)					Before thick mats form							
	Water fern				Before thick mats form and spores are released								
Rooted Floating-leaved	Broad-leaved pondweed												
	Water-lillies												
	Fringed water-lily												
	Arrowhead												
	Floating pennywort												
	Water-primroses												
Tall Emergent	Common reed												
	Reedmaces												
	Reed sweet-grass					Can reduce summer flood risk							
	Reed canary-grass												
	Common club-rush												
	Branched bur-reed							Before first frosts					
	Tall sedges					Can reduce summer flood risk							
Broad-leaved Emergent	Fool's water-cress												
	Lesser water-parsnip			Before Flowering					Treat Re-growth				
	Water-cress												
	Water solider (emergent parts only)												
	Australian swamp stonecrop (emergent)												
Non-native Invasive Bank Species	Japanese knotweed								Applied to mature plant when flowering				
	Himalayan balsam				Before Flowering								
	Giant hogweed			Before Flowering									
			Optimal treatment period					Sub-optimal treatment period					

Figure 7.3 Indicative timings for management of species groups using glyphosate-based herbicides

Best practice working methods

A selective approach is necessary when carrying out aquatic and riparian vegetation management using glyphosate-based herbicides. Although glyphosate-based herbicides are non-selective, a careful and targeted application method can help to ensure that only the problematic species are treated.

More precise application methods, such as hand-held weed wipers or knapsack sprayers are a good way of ensuring a selective spraying approach is adopted. This reduces costs and also minimises the impact on non-target species. It can also be used to retain a fringe of vegetation along the toe of the bank for wildlife and bank stabilisation purposes.

There are different approaches to how and to what extent vegetation can be managed within a channel using herbicide to bring both flood risk management and biodiversity benefits. Further information can be found in:

- *The Drainage Channel Biodiversity Manual* (Buisson et al. 2008)

A non-selective approach to spraying can worsen problems with aquatic and riparian vegetation. For example, spraying all tall emergent vegetation may encourage the growth of floating or submerged species, or algae, which can be equally as problematic and require management.

Benefits	Disadvantages
Cost-effective and relatively inexpensive compared with physical techniques.	There is a lag time between application and realisation of the benefits. This technique cannot be used in critical flood risk situations that require rapid solutions.
Spraying can be conducted rapidly over long lengths of watercourse.	Risk (although very low) of deoxygenation as plants die back and decompose.
Longer-term benefits can be achieved in terms of reduced regrowth which may last for up to three seasons (depending on species).	Cannot be used on submerged species or algae.
Due to the longer-term impact a lower frequency of management will be required compared with physical techniques. Less intervention and habitat disturbance will be needed.	Herbicide applications are constrained by weather conditions and require a high degree of flexibility. There may be few windows with suitable weather conditions when treatment can be undertaken.
	Herbicides are not likely to be effective where vegetation has been damaged by cutting, grazing, flood waters or frosts.
	It is a non-selective herbicide and can impact on non-target species.
	Potential adverse public perception associated with the use of chemicals.

Sources of further information on herbicides and methods of application

- The Herbicide Handbook: Guidance on the Use of Herbicides on Nature Conservation Sites (Britt et al. 2003)
- Code of Practice for Using Plant Protection Products (Defra 2006)
- Chemicals Regulations Directorate (www.pesticides.gov.uk/guidance/industries/pesticides)

Key considerations

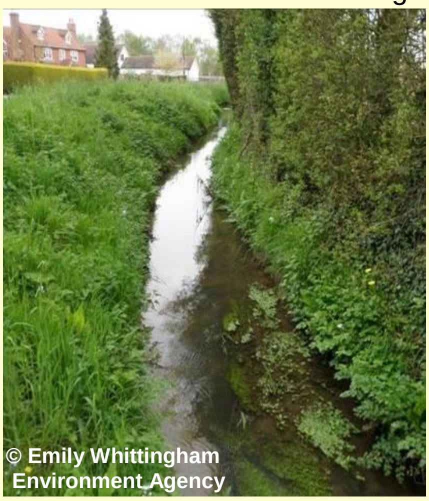
- **Licensing and consenting** – agreement must be obtained from the Environment Agency/ Natural Resources Wales to use herbicides in or near water.
- **Operators –** herbicides must only be used by appropriately trained operators holding the correct NPTC.
- **Chemicals used:**
  - All herbicide treatment must be carried out in accordance with the instructions printed on the product label.
  - The selected glyphosate-based herbicide must have a label stating that it can be used in or near water.
- **Timing** – spraying should be carried out at the optimal time for the problem species.
- **Selective control** – a selective approach to spraying should be adopted with as much in-channel vegetation retained as possible.
- **Weather conditions –** a flexible approach to treatment should be adopted to take into account weather conditions.

Example: Collier Street Stream, Kent

Between the villages of Marden and Yalding, near Maidstone in Kent, the Collier Street Stream causes localised flood risk management issues due to dense growth of broad-leaved emergent species (lesser water-parsnip *Berula erecta*, fool's water-cress *Apium nodiflorum* and water-cress *Rorippa nasturtium-aquaticum*). This relatively narrow watercourse, only 1–3 m wide, is a tributary of the River Medway and can become choked by these species, reducing channel capacity and impeding flows.

The stream is managed by the Upper Medway IDB. Mechanical management with a weed cutting bucket has been used in previous years. Due to the potential cost benefits, the use of chemical control using a glyphosate-based herbicide was trialled in 2013, in agreement with the Environment Agency.

Due to the problems caused by these broad-leaved emergent species a selective approach to spraying was adopted, with only the large problematic patches spot-treated in summer using a knapsack sprayer. In narrower sections of the channel, 20% of the vegetation was retained either side, increasing to 50% in wider sections. The spraying treatment was not as successful as hoped and mechanical removal was also needed. In the future, spring and summer application will be conducted and where possible, alternate lengths will sprayed to create a sinuous channel and refuge areas for Water Voles.



7.4.2 Barley straw and barley straw extract

Summary: Management of watercourses where algae are problematic through the application of barley straw and chemicals derived from decomposing barley straw.

Cost: ££

Short–medium term option

This technique can only be used on filamentous green algae, unicellular green algae and cyanobacteria. It cannot be used for the management of stoneworts (charophytes) or any other aquatic and riparian plants. It is also not effective in muddy waters.

This technique is discussed in the chemical technique section as, although not a herbicide, the decomposition process of barley straw produces chemicals which inhibit the growth of filamentous green algae, unicellular green algae and cyanobacteria.

The technique can be used to manage problematic areas of algae either through the direct deployment of barley straw within a watercourse, or through using a specialist extract derived from the decomposition process.

No adverse effects on aquatic fauna or vegetation have been found when using barley straw, and similar natural algae inhibitors are derived from the decomposition of deciduous leaf litter, which are common inputs to watercourses.

Barley straw

When deploying barley straw in a watercourse it can either be done as bales, by filling nets with straw to create barley straw ‘sausages’, or by filling gabion baskets. The following principles should be adopted.

- Apply straw twice each year, preferably in early spring before algal growth starts and then again in autumn.
- The minimum effective quantity of barley straw in still or very slow flowing water is about 10 grams of straw per square metre of water surface (g/m^2), with a maximum dose of 25 g/m^2.
- The volume of straw required in flowing waters is uncertain. It has been used effectively in the field by placing quantities of straw at intervals along either bank of the watercourse. The distance between straw masses has usually been between 30 and 50 m and the size of each straw mass was chosen, for convenience, as about one bale (20 kg).
- In flowing waters, anchor the barley straw bales/ nets securely to prevent them becoming dislodged and floating downstream causing blockages.

- Spacing of nets does not need to be exact. Practical considerations such as navigation or fisheries may influence the number and placement of nets.
- It is preferable to apply several small quantities of straw to a water body rather than one large one. This improves the distribution of the active factors throughout the water body.
- Barley straw works more effectively and for longer periods than wheat or other straws and should always be used in preference. If barley is unavailable, other straws including wheat, linseed, oil seed rape, lavender stalks and maize can be used as a substitute. Do not use hay and green plant materials as they release nutrients which may increase algal growth; they also rot very rapidly and may cause deoxygenation.
- Straw should be loose, allowing water to pass through to aid decomposition in well-aerated conditions. If applied in large compact masses such as bales, or to very sheltered and isolated areas of water, there will be insufficient water movement through it and conditions will become progressively anaerobic limiting the control of algae. Anaerobic decomposition can produce chemicals that stimulate the growth of algae.
- Straw works best if it is held near to the surface where water movement is greatest.
- Do not apply straw during prolonged periods of hot weather to waters containing dense algal blooms, as the combined oxygen demand from the algal bloom and the straw could temporarily increase the risk of deoxygenation which may lead to the death of fish.
- If the straw starts to smell, it is not working and should be removed.

Further information

- *Control of Algae with Barley Straw* (CAPM 2004)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The process is temperature-dependent, being faster in summer than in winter, taking six to eight weeks for the straw to become active in water temperatures of below 10ºC, but only one to two weeks when water temperature is above 20ºC.

Algal growth before the straw becomes active will continue, but once the straw has started to release the chemicals it will remain active until it has almost completely decomposed. The duration of this period varies with the temperature and the form in which the straw is applied, but can be between four and six months.

The time taken for effective control varies with the type of alga with small, unicellular species usually disappearing within six to eight weeks, but larger filamentous green algae often surviving for longer periods. Filamentous green algae may not be controlled adequately in the first season if the straw is added too late in the growing season.

Barley straw extract

Although used primarily as a treatment for algal blooms in domestic ponds, barley straw extract may have some application in the treatment of watercourses. It will only be successful in slow-flowing and stagnant watercourses, but may offer a solution to the treatment of relatively long lengths of watercourse as it can be easily applied and it will overcome any access restrictions where straw bales or nets cannot be applied directly to the watercourse.

Benefits	**Disadvantages**
Relatively inexpensive method of treatment for problematic areas of algae.	Cannot be used on stoneworts (charophytes) or other aquatic and riparian vegetation.
No known undesirable side-effects.	Installing straw bales/ nets/ baskets into watercourses may trap debris, or they may become dislodged themselves and cause blockages.
Can be used in a variety of watercourse types.	Regular monitoring and maintenance may be required when using barley straw bales/ nets/ baskets as they require being left in the watercourse for several months; this can increase costs.
Suppression of algal growth with barley straw/ barley straw extract can allow other aquatic vegetation to recolonise, which in turn further suppresses algal growth and the need for re-treatment.	Deoxygenation may occur as part of the decomposition process, particularly in hot weather.
Invertebrate populations reportedly increase substantially around barley straw in watercourses which can provide a useful food source for fish.	Uncertainty on the exact methodology of this technique in flowing waters.

Key considerations

- **Flood risk implications** – the flood risk implications of using barley straw bales/ nets/ baskets should be considered carefully – they need to be anchored securely to the bank.
- **Monitoring** – regular monitoring of the barley straw bales/ nets/ baskets is necessary to ensure they remain effective and are not causing additional problems to that which they are treating.

7.5 Environmental techniques

This section discusses available environmental techniques to manage aquatic and riparian vegetation. This group of techniques aim to modify the conditions within or surrounding a watercourse to make it less favourable to the species of plant requiring control. It is important to have a thorough understanding of a species' ecology so that the environment can be manipulated to limit its growth. Factors that can be modified include the following.

- **Light**. Plants require light for photosynthesis. The growth of a number of aquatic and riparian plant species can be reduced or stopped through shading, created by a variety of methods.
- **Water levels**. Plants have specific water level tolerance limits, above and below which their growth is reduced or eliminated. Altering water levels to be outside the tolerance limits of the problem species can aid their control.
- **Flow characteristics.** Plants have specific water flow tolerance preferences; some prefer fast flow conditions whereas others inhabit only stagnant and slow-flowing waters. Flow rates that are faster or slower than these preferences may help to limit the growth of, or remove/ dislodge, the problem species and help in its control.
- **Water quality.** Over recent years nutrient enrichment of watercourses across England and Wales has exacerbated many aquatic and riparian vegetation problems, leading to increased growth. The management of nutrient inputs to watercourses may, in the long term, reduce the problems currently faced by watercourse managers.

In addition to techniques which manipulate these characteristics to influence the distribution and extent of aquatic and riparian vegetation, creation of disturbance can also reduce aquatic plant issues. In navigable waterways, boats can create water and sediment disturbance and increase turbidity, which in turn limits aquatic plant growth; this could provide an additional option for vegetation control. This is unlikely to be implemented purely for the purposes of vegetation control. The reduction in aquatic plant issues in navigable channels is usually the incidental result of boating and navigation activities and it is not given a specific section in this guide.

The use of boat traffic to manage vegetation can be problematic as controlling the levels of boat traffic can be difficult and the technique is unselective, affecting all susceptible plants within the channel. Boats can also carry non-native invasive species, resulting in their spread. Where boat traffic is heavy, losses in aquatic plant diversity and value for fisheries and wildlife have been reported and using boat traffic to create disturbance is not recommended as a specific vegetation management technique. The restoration of boat traffic to channels previously not navigable should be carried out with caution and only following detailed environmental assessment as it could adversely impact on a wide range of species, including those which are protected and rare.

In general, environmental techniques can be expensive and are typically long-term management strategies that can take several years, often decades, to have an effect. Due to their long-term effect they can be cost-effective compared with physical or chemical control techniques when costs are compared over a longer period of time. They also tend not to be used in isolation, often being combined with shorter-term physical and chemical techniques until they become effective, or carried out in combination with other capital works.

7.5.1 Shading with vegetation

Summary: All plants require light to photosynthesise and some species are intolerant of shade. Using tall vegetation to restrict light to problem species to limit their growth can be an effective management technique. There are several methods of creating shade with vegetation.

Cost: £ – ££

Long-term option

This technique is very effective for:

- submerged species – though not for mare's-tail *Hippuris vulgaris*, rigid hornwort *Ceratophyllum demersum* and waterweeds *Elodea* spp. are these are relatively tolerant of low light levels
- free-floating species
- rooted floating-leaved species
- broad-leaved emergent species

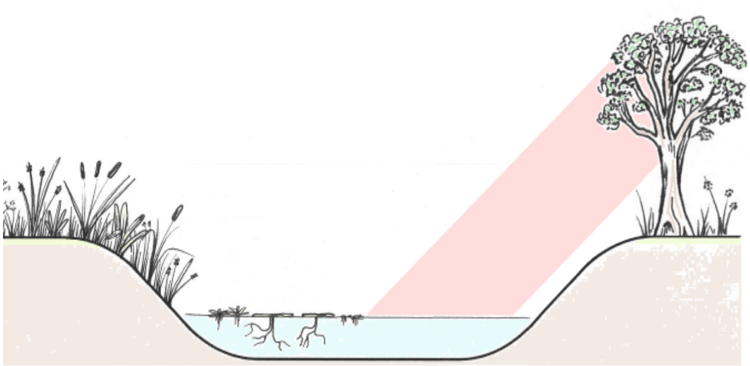
In general, light levels need to be reduced by 35–95% for vegetation growth to be reduced sufficiently for the technique to be successful.

Unbroken, dense shade will have an adverse impact on watercourses, reducing species-richness. It is advised that only intermittent shade is created and targeted at problem areas.

Shading through tree/ hedgerow/ bankside planting

The planting of trees and hedgerows along a watercourse can be an effective method of managing aquatic and riparian vegetation.

This technique is most effective on narrower channels. On wider channels shading can be used to manage marginal vegetation, although central parts of the channel will be unaffected.



It is most effective on watercourses orientated east–west so that planting can be undertaken on the southern bank, if only one bank can be planted. Trees should be located as close to the water's edge as possible.

Different tree species have varying canopies that generate different levels of shade. The species selected should also be able to withstand periodic inundation.

Suitable species for large channels (>5 m wide) include alder *Alnus glutinosa*, black poplar *Populous nigra* and various species of willow *Salix* sp. These species are all relatively rapid growing and will give results in 5–10 years. Lime *Tilia cordata*, beech *Fagus sylvatica*, oak *Quercus* sp., and field maple *Acer campestre* could also be used, but they grow much more slowly so the effects would not be realised for a considerable period of time. Coniferous species should not be used as their needles impact on water chemistry.

On smaller channels (<5 m wide) shrubs including elder *Sambucus nigra*, blackthorn *Prunus spinosa* and hawthorn *Crataegus monogyna* can be effective at generating shade, as can coppiced alder and willows.

Tree or shrub planting is a long-term option and will take 5–10 years or more, depending on the tree species used to start to have an effect. Management over the short term to aid establishment is also likely to be required, potentially involving fencing to prevent grazing pressures and treatment of any weed growth around saplings.

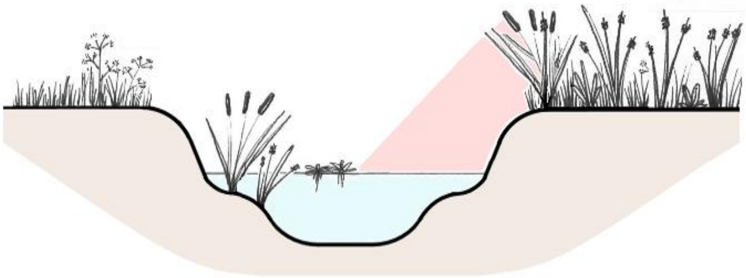
In the long term, it is necessary to consider the management of trees along watercourses. Some pruning of low-hanging branches, which may pose an obstruction to flow or trap debris, may be required.

Planting of trees and hedgerows alongside watercourses also restricts access for management using other techniques. Where bankside vegetation is particularly species-rich and/ or where rare plant species are present, this technique is discouraged as their growth could also be reduced by the shade generated.

Benefits	**Disadvantages**
Can provide habitat for a number of other species (for example, otter *Lutra lutra*, fish, birds and bats).	Dense shading can result in reduced species-richness of bankside and in-channel habitats.
Roots can help to stabilise banks and reduce bank erosion.	Trees and hedgerows can restrict access to watercourses for other management operations (for example, de-silting).
Trees/hedgerows and bankside vegetation can act as a buffer intercepting run-off and helping to improve water quality.	Dense planting can result in large accumulations of leaf litter.
	Roots can damage field drainage pipes - trees/ hedgerows should not be planted where this is present.

Fencing to allow bankside growth for shading

Fencing of watercourses to allow bankside vegetation to grow ungrazed and uncut may also provide sufficient shading for narrow watercourses (those less than about 2 m in width). Tall marginal vegetation such as common reed *Phragmites australis*, reedmaces *Typha* spp. or reed sweet-grass *Glyceria maxima* will generate shade and limit growth of in-channel submerged, floating and broad-leaved emergent species. Other species that can often be found growing in riparian zones when ungrazed and uncut can also be used to generate shade, such as great willowherb *Epilobium hirsutum, m*eadowsweet *Filipendula ulmaria* and hemlock *Conium maculatum*.



Benefits	**Disadvantages**
Can provide habitat for a number of other species (for example, cover for small mammals, nesting habitat for birds).	Dense shading can result in reduced species-richness of bankside and in-channel habitats.
Can help to stabilise banks and reduce bank erosion.	Woody vegetation will eventually become established and this will require management.
Bankside vegetation can act as a buffer intercepting run-off and helping to improve water quality.	Livestock access to watercourses can be beneficial in some instances and restricting access will stop these benefits.
	Shade generated from the growth of bankside vegetation is generally uncontrollable and may not generate sufficient shade, or shade in the right locations, to be an effective technique.
	Management of tall emergent vegetation may still be required as it can itself become problematic, particularly when it dies back.
	Tall emergent species can accumulate silts within their root and rhizome networks, expanding the area they can colonise. Eventually they may encroach across the full width of the channel and require management.

Shading with native, broad-leaved floating species

Native plants with a dense cover of floating leaves, for example water-lilies and broad-leaved pondweed *Potamogeton natans*, may also be effective at controlling submerged plant growth by reducing the light available beneath the water surface. This technique is only effective on submerged species and algae.

Benefits	Disadvantages
In-channel species diversity can be increased.	Floating broad-leaved species used to control the submerged species may themselves become problematic over time and require management.
	Risk of deoxygenation as submerged species die back. The risk is, however, low as total surface coverage is rare.

Key considerations

- **Long-term management –** in the long term the vegetation planted or encouraged to grow along a watercourse will need to be managed.
- **WFD implications** – shading may compromise achievement of WFD objectives by permanently reducing aquatic plant cover and richness.
- **Species selection** – plants should be native, locally sourced and appropriate for the area.
- **Consent** –flood defence byelaw or land drainage consent must be obtained for tree/ hedgerow planting or fence erection from the Environment Agency/ IDB/ LLFA.
- **Access implications –** vegetation on banksides can restrict access for other management operations.

Useful sources of information

- Environment Agency FCRM Asset Management Maintenance Standards
- *The Drainage Channel Biodiversity Manual* (Buisson et al. 2008)
- *Woodland for Water: Woodland Measures for meeting Water Framework Directive Objectives* (Nisbet et al. 2011)

7.5.2 Shading with materials

Summary: All plants require light to photosynthesise and some species are intolerant of shade. Shading using man-made materials, either suspended above or submerged below the water surface, can be an effective management technique.

Cost: £££

Medium-term option

This technique involves limiting light penetration into the water using sheets of opaque material either floating on the water surface or suspended above it. In trials undertaken in the 1980s the length of time required to effectively control different species using floating material varied with water-crowfoot *Ranunculus* spp. taking 5–8 weeks, water-cress *Rorippa nasturtium-aquaticum* taking 6–9 weeks and waterweeds *Elodea* spp., branched bur-reed *Sparganium erectum* and common reed *Phragmites australis* taking 12 weeks. When suspended above the watercourse the effect of shading was found to be less effective than when floating.

Due to a large number of constraints and disadvantages, this technique is rarely used as a method for aquatic vegetation control.

Benefits	**Disadvantages**
Effective on small, localised infestations.	Cannot be used over long lengths of watercourse.
Effects can be relatively long term.	Non-selective technique; all species beneath the barrier will be impacted.
Most effective on still and very slow-flowing watercourses.	Unsightly.
	Floating/ suspended materials interfere with fishing and boating activities.
	Rapid deoxygenation can occur in the water beneath the floating/ suspended material.
	Requires frequent monitoring and maintenance.
	Very expensive.
	Can detach and cause downstream blockages.

Shading with benthic barriers

Shading can also be achieved below the water surface using a suitable material, or ‘benthic barrier’, to shade the channel bed. Plastic sheeting is often used, but presents difficulties in that it is hard to sink and secure, particularly in flowing waters.

The technique has been trialled using biodegradable jute matting, on Lough Corrib in Ireland to control curly water-thyme *Lagarosiphon major*. Jute matting has advantages over plastic in that, once saturated, it sinks. This type of material is more appropriate in flowing watercourses, although it needs to be firmly anchored in place. Being biodegradable it can remain in place and may help in stabilising the bed, which could be disrupted by the sudden death of the target species. Jute barriers are also gas and water permeable. They also allow some movement of invertebrate species through them.

Benefits	Disadvantages
Effective on small, localised infestations.	Cannot be used over long lengths of watercourse.
Effects can be relatively long term.	A non-selective technique; all species beneath the barrier will be impacted.
Biodegradable materials may have benefits for bed stability as plants die back.	Can be unsightly.
	Nutrient exchange between sediments and water is disrupted, particularly when using plastic sheeting.
	Gasses from decay beneath the sheet cannot escape if using plastic sheeting, potentially resulting in deoxygenation.
	Requires frequent monitoring and maintenance.
	Very expensive.

Key considerations

- **Monitoring –** any material introduced into the environment must be carefully managed and monitored to ensure it continues to be fit-for-purpose and does not cause other problems.
- **Environmental impacts –** the risk of deoxygenation should be considered carefully.
- **Consent** –consent is likely to be needed from the Environment Agency/ Natural Resources Wales if the watercourse is a Main River, or the IDB/ LLFA if it is an Ordinary Watercourse.

7.5.3 Dyes

© Catherine Chatters, Hampshire and Isle of Wight Wildlife Trust

Summary: Plants require light to photosynthesise and some species are intolerant of shade. Preventing light penetration of the water column through the use of dyes can be effective at controlling some species.

Cost: £

Short-term option

Limiting light penetration of the water column can be achieved through the use of specialist dyes, usually in black or blue. There are several dyes that are commercially available which colour the water and absorb sunlight, preventing light penetration.

© Catherine Chatters, Hampshire and Isle of Wight Wildlife Trust

The use of dyes to control aquatic vegetation tends to be for ponds rather than watercourses. This technique **cannot be used on flowing waters**, only static, usually small ones, such as ditches. It is a technique that can be used on submerged species and algae and, as the dye is applied early in the growing season, potentially other species of aquatic plant that have yet to develop emergent or floating leaves.

Dyes should be applied before the target species has started to grow; this can be as early as mid-February. Dyes should then be topped up every month at 10% of the initial dose rate to maintain control throughout the season as the pigment breaks down and becomes diluted by rain.

Initial application of dye must not be made during the summer as this can cause rapid die-back of plants and carries the risk of deoxygenating waters. Water temperatures for application should be below 8–10°C.

Benefits	Disadvantages
No major adverse effects on non-target organisms have been reported.	Cannot be used over long lengths of watercourse.
Can be effective on small, localised infestations, particularly of non-native invasive species.	Can only be used on species which have submerged parts and algae.
No specific consents/ licenses are	Cannot be used on flowing

Benefits	Disadvantages
required to use dyes.	watercourses, although it may be suitable for on-line ponds with higher water retention times.
	Non-selective technique; all plants beneath the dye will be impacted upon.
	Can be unsightly.

(c) Catherine Chatters, Hampshire and Isle of Wight Wildlife Trust

Key considerations

- **Water use** – cannot be used where water is used for human consumption and may be undesirable in an amenity setting
- **Monitoring** – this will need be necessary to ensure the dye remains effective
- **Watercourse type** – limited applicability in static waters only

Example: Use of dyes at Maidenhead Sailing Club

Many sailing clubs, including that at Maidenhead, carry out management of aquatic vegetation so that it does not impede recreational activities. Past management methods have involved the use of herbicides (now unavailable for submerged species) or physical techniques such as cutting. From 2011 onwards, Maidenhead Sailing Club has been experimenting with the use of blue dye to control submerged species including Canadian waterweed *Elodea canadensis*.

The first deployment of dye in 2011 was initially successful. However, low water levels allowed the submerged plants to regrow and physical techniques were also required to prevent sailing activities being impeded. In 2012 greater success with dyes was achieved, with the use of physical techniques limited to shallow/difficult areas. The deployment of 105 litres of blue in 2013 achieved good control and higher water levels ensured the issues encountered in 2011 did not recur. As a result the use of physical control techniques was discontinued.

The following conclusions were made after the trials (Dibble 2013).

- Blue dye does control submerged aquatic vegetation, but monitoring is needed to ensure dye concentration is sufficient and that algal growth does not occur.
- Care needs to be taken in shallow water where evaporation can bring plants to the surface and photosynthesising environment, making the dye ineffective.
- Integrated use of dyes with targeted physical control has been successful.
- Growth of other aquatic and riparian vegetation, including reeds and water lilies was unaffected, and no decline in bird activity was reported.
- Stakeholder engagement with all water body users and authorities is important.

While this example relates to a lake environment, the technique and lessons learnt can be applied to static watercourses.

7.5.4 Water level manipulation

Summary: Plants have specific water level tolerance limits within which they grow. Altering water levels to be above or below these tolerance limits can help to reduce the growth of, or eliminate, problematic species.

Cost: ££ – £££

Medium–long term option


© Murray Bush, Environment Agency

All plants have preferred environmental conditions within which they will grow, with the depth of water, or soil water table, a key factor for aquatic and riparian vegetation. For example, yellow water-lily *Nuphar lutea* can grow in water up to 2 m deep, whereas branched bur-reed *Sparganium erectum* can only tolerate water around 0.5 m deep.

Manipulating water levels to be deeper than these preferred limits can help to control the growth of some species. Similarly, drawing down water levels and draining channels temporarily can make conditions unsuitable for other species.

Raising of water levels

There are several possible ways in which water levels can be raised, either permanently or temporarily, to control problematic species. The use of structures such as sluices and weirs or pumping stations can be an effective way of doing this where this infrastructure is present. This is only likely to be effective over localised lengths of watercourse, but can be a useful way of managing aquatic and riparian plants in some situations.

Structures could be installed specifically to raise water levels for vegetation management. This work will need consent (see section 4.4.11) and may also fall under the remit of the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended) and require detailed environmental assessment prior to undertaking (for further information see section 4.4.6). Structure installation would also be much more expensive than using existing infrastructure.

If water levels are only raised temporarily, the timeframe required to ensure that growth is reduced significantly, or eliminated, will vary with the species. Regular monitoring should be conducted throughout the period that water levels are raised to determine the impact on the problematic species and the length of time by which water levels need to be raised. Also, once water levels are returned to their usual level, the problem species may begin to recolonise the watercourse if not completely killed off.

The environmental impacts of raising water levels, both permanently and temporarily, need to be carefully considered. Where field drainage systems are present, raising water levels may make these ineffective, leading to waterlogging of soils and localised flooding. Care must also be taken to ensure that the weakening of emergent plant species using this technique does not destabilise banks. Also changing the water levels impacts on other species, for example, water vole *Arvicola amphibius* burrows may be inundated and terrestrial bankside species may be drowned out.

Benefits	Disadvantages
Existing water level management structures can be used, where present.	Non-selective technique and all species within the channel where water levels are raised will be impacted upon. This will include terrestrial bankside plant species and also potentially water voles *Arvicola amphibius*.
Relatively cheap option where existing water level management infrastructure is used.	Expensive option where new water level management infrastructure is required.
	Field drainage systems may be made ineffective, leading to waterlogging.
	Only feasible on certain watercourse types, where appropriate structures/ pumping stations are present.
	Monitoring of vegetation growth will be required throughout.

Water levels can also be increased by excavating the channel to make it deeper. In most circumstances this is not advised purely as a vegetation management technique as it would involve large-scale earthworks which would be environmentally damaging. It could also create issues with bank stability, require the disposal of significant volumes of spoil and impact on the hydromorphology of the channel. As part of other capital works programmes, it may be possible to incorporate some deepening of the channel to make conditions unsuitable for problematic species. For example, as part of channel reprofiling or regrading works where tall emergent species are problematic, the channel could be designed so that the central section is too deep for the species concerned. Marginal areas, or a shelved bank/ berm, should be retained so that these species are not completely eradicated to be beneficial for wildlife and bank stabilisation purposes.

Channel reprofiling and/ or re-grading will need consent (see section 4.4.11) and may also fall under the remit of the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended) and require detailed environmental assessment prior to undertaking (for further information see section 4.4.6).

The required water depths to limit the growth of certain species are given in Table 7.2.

Table 7.2 Required water depths to limit growth

Water depth	Species Intolerant of given water depth
+ 0.5 m	Reed canary-grass, branched bur-reed, tall sedges, lesser water-parsnip (may tolerate waters up to 0.6 m)
+ 1 m	Water-starworts, arrowhead, floating pennywort, common reed, reed sweet-grass
+ 1.5 m	Fringed water-lily, reedmace spp., common club-rush
+2 m	Broad-leaved pondweed, water-lilies, curly water-thyme (water depths of +4 m likely to be needed)

Lowering of water levels/ draining

Temporary lowering of water levels or the complete draining of sections of channel can be carried out to make conditions unsuitable for a range of submerged species.

Complete draining of the channel has found to be effective at eradicating Canadian waterweed *Elodea canadensis*, and is often used with chemical control techniques in the management of Australian swamp stonecrop *Crassula helmsii*. This technique not only stresses the plant through drying, but also exposes it to high summer temperatures and winter frosts, helping to reduce its growth and potentially eliminate it.

This technique is unlikely to be feasible in larger watercourses and the environmental impacts need to be carefully considered, for example, fish passage will be temporarily affected by damming off and draining a section of watercourse. Over-pumping is likely to be required to ensure that water can continue to flow past the drained section.

The timeframe required for draining to ensure that growth is reduced significantly, or eliminated, will vary with the species. Regular monitoring will be needed throughout the period of draining to determine the impact and the length of time draining is required. Once water levels are returned to the usual level, the problem species may begin to recolonise the watercourse if not completely killed off.

Benefits	**Disadvantages**
Existing water level management structures may be able to be used, where present.	Non-selective technique and all species within the channel where water levels are lowered/ drained will be impacted. For example, aquatic macroinvertebrates and water voles *Arvicola amphibius* would be adversely affected.
Could be carried out in combination with other capital works schemes.	Fish passage will be adversely impacted.
	Expensive option where new water level management infrastructure is required or excavations are required.
	Not feasible on large watercourses.
	Frequent monitoring of vegetation growth will be required throughout.

Key considerations

- **Environmental impact –** careful assessment is needed of the impact on non-target species, in particular protected fauna such as water vole, aquatic macroinvertebrates and fish, and also the wider environment. Appropriate mitigation will need to be implemented if necessary. The works may also fall under the remit of the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended).
- **Cost –** an expensive option where structure installation or earthworks are required.
- **Consent –** consent will be needed from the Environment Agency/ Natural Resources Wales if the watercourse is a Main River, or the IDB/ LLFA if it is an Ordinary Watercourse.
- **Land drainage –** implications of raising water levels for land drainage need to be considered.
- **Watercourse size –** this technique is only likely to be suitable for smaller watercourses.

7.5.5 Manipulation of flow characteristics

Summary: Plants have specific water flow requirements within which they grow. Increasing flow rates to faster than the problem plant species can tolerate can help to reduce the growth of, or eliminate, them.

Cost: ££ – £££

Medium–long term option

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All plants have preferred flow conditions in which they will thrive. Some plants, such as water-crowfoots *Ranunculus* sp. and fennel pondweed *Potamogeton pectinatus* are tolerant of relatively fast-flowing waters, whereas others such as rigid hornwort *Ceratophyllum demersum* or duckweeds *Lemnaceae* are only tolerant of static or slow-flowing waters. Generally, faster flowing waters support fewer species. Increasing flows can help to limit excessive plant growth and discourage certain plants from colonising the watercourse.

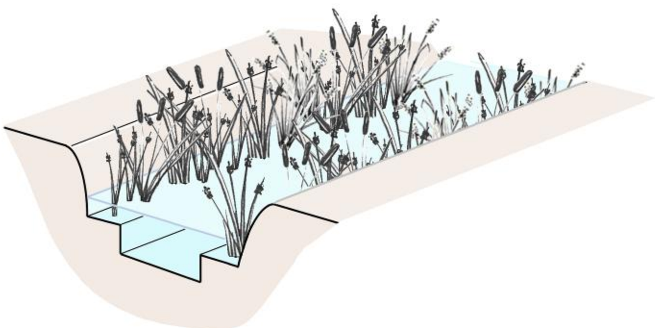
Increasing flows can also dislodge some plants such as duckweeds or rigid hornwort *Ceratophyllum demersum*, reducing the problem at one particular location, although this may displace the issue downstream. Increasing flows and dislodging species can also be problematic where non-native invasive species are concerned as this can facilitate their downstream spread.

Higher flow rates can help to scour out silts from the channel bed. In certain watercourse types this can be of benefit by exposing bed substrates such as gravels, in which fewer plant species can generally root.

Alteration of flow characteristics is not recommended without advice from a geomorphologist.

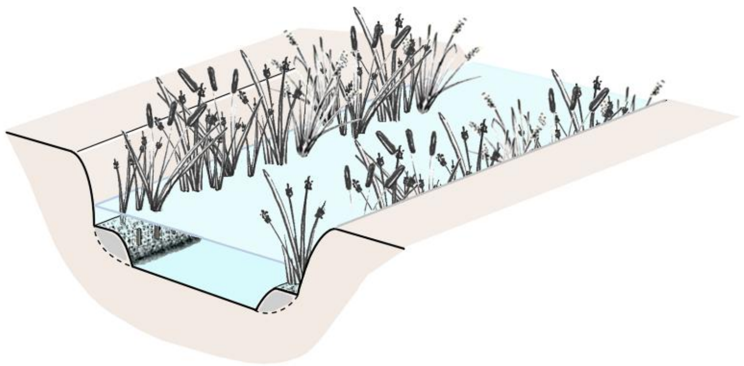
Channel narrowing to increase velocity (two-stage channel)

One method of increasing flow rates involves watercourse narrowing so that flow is concentrated in a narrower central channel. This increases flow velocity resulting in conditions which may become unsuitable for the problem species.



Channel narrowing could be achieved through extensive earthworks to create a two-stage channel. A two-stage channel would have a relatively narrow, deeper channel, with shallower berms along the banks. This increases cross-sectional area and can be of benefit in reducing levels of flood risk, while leaving the channel bed intact.

Earthworks of this magnitude are environmentally damaging in the short term and also require the disposal of significant volumes of spoil. In the long-term, works such as this can be beneficial by increasing in-channel habitat and geomorphological diversity of benefit to a range of species. The creation of a two-stage channel will need consent (see section 4.4.10) and may also fall under the remit of the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended) and require detailed environmental assessment prior to undertaking (for further information see section 4.4.6).



A similar two-stage channel form could also potentially be produced by installing materials such as coir rolls along the toe of the bank. This technique could be appropriate in channels that have been over-widened by excessive dredging operations or erosion.

Benefits	**Disadvantages**
Could be undertaken in combination with other capital works schemes.	Very expensive.
Can help to deliver environmental benefits in over-widened channels in the long term (for example, cleaning of bed gravels).	Non-selective technique and all species within the channel where flow characteristics are affected will be impacted upon.
	Significant earthworks to create two-stage channel are environmentally damaging in the short-term.
	Difficult to achieve in lowland areas where channel gradients are shallow.

Manipulation of flow characteristics

Manipulating flow characteristics at a temporary, localised level could also be undertaken by altering pumping regimes. This is only likely to have an impact along short sections of watercourse (for example, within the pump outlet channel itself) in relatively close proximity to the station.

Similar flow processes to those within a two-stage channel can also be created in channels where tall emergent species are present by managing the vegetation in a way to encourage flows along a preferred narrow path through either physical or chemical means. Managing vegetation in the central part of the channel encourages water to flow along this pathway, potentially making it unsuitable for problematic submerged or floating species. Again this technique may be useful in over-widened channels.

Benefits	Disadvantages
Relatively cost-effective.	Unlikely to be a feasible option in all watercourse types – limited applicability.
Can help to deliver environmental benefits in over-widened channels (for example, retention of marginal vegetation, cleaning of bed gravels).	Non-selective technique and all species within the channel where flow characteristics are affected will be impacted.
Existing water level management structures may be able to be used, where present.	Increased energy costs will be associated with increased pumping.

Key considerations

- **Environmental impact** – careful assessment is needed of the impact on non-target species, in particular protected fauna such as water vole, aquatic macroinvertebrates and fish, and also the wider environment. Appropriate mitigation will need to be implemented if necessary. The works may also fall under the remit of the Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999 (as amended).
- **Consent** – consent is needed from the Environment Agency/ Natural Resources Wales if the watercourse is a Main River, or the IDB/ LLFA if it is an Ordinary Watercourse.
- **Cost** – where earthworks are required, this is an expensive option. Where pumping is used, increased energy costs need to be considered.

7.5.6 Nutrient management

Summary: Nutrient enrichment of watercourses over recent decades has worsened many aquatic and riparian plant problems in the UK. Management of nutrient inputs to watercourses may help to reduce problems in the long term.

Cost: ££ – £££

Long-term option

Pollution and nutrient enrichment alter the natural composition of aquatic and riparian vegetation in watercourses. Species known to be tolerant of pollution and to favour high nutrient levels include several of the most problematic native species including:

- fennel pondweed *Potamogeton pectinatus*
- broad-leaved pondweed *P. natans*
- spiked water-milfoil *Myriophyllum spicatum*
- filamentous green alga, including *Cladophora spp*.

Pollution sources to watercourses can be diffuse (that is, surface water run-off from the land, particularly agricultural land) or from point sources (for example, storm sewer and industrial outfalls, septic tank discharges). Rainfall and atmospheric deposition can also introduce pollutants and nutrients to watercourses, as can erosion of banks which can result in nutrient-rich sediments entering the watercourse.

Phosphorus, and to a lesser extent nitrogen, are the nutrients recognised as having the greatest impact on vegetation in watercourses. Algal and other vegetation growth in most surface waters is naturally limited by phosphorous, and increased levels of this nutrient in particular can lead to a rapid increase in cover.

A number of techniques can be used to reduce the input of nutrients and pollutants to watercourses. These are generally long-term strategies that may take several years or decades to realise the benefits, but once they start to have an effect the management requirements of watercourses should reduce. These techniques may be combined with other methods of management in the short term.

Buffer strips

Landscape scale changes in agricultural practices and integrated agri-environmental land management approaches are often an effective way of reducing nutrient inputs to watercourses. Buffer strips adjacent to watercourses are one method of protecting watercourses from diffuse pollutant inputs from surface water run-off.

A buffer strip is the vegetated area of land between the watercourse and the agricultural or other land use. The vegetation can consist of grassland, wetland, scrub or trees, and it provides a physical and biological barrier to restrict the flow of pollutants from the adjacent land into the watercourse.

For a basic grass buffer strip, a width of 6–8 m alongside the watercourse is recommended, although the larger the buffer the greater the benefits and reduced inputs. Riparian buffers are best suited to help with reducing run-off on light sandy and silty soils, chalk and limestone soils, on shallow gradients (2–11°). On steeper slopes buffer strips at least 10 m wide are likely to be needed.

Effective buffer strips require the establishment of a dense grassy sward; this can either be achieved by natural regeneration or sowing. Additional protection, such as a mulch or geotextile, may also be needed to prevent increased run-off during establishment. The environmental benefit of buffer strips can be increased by using a species-rich seed mix containing a range of native wildflower species which will provide a source of nectar for invertebrates and seeds for birds.

Do not use heavy machinery along the buffer strip during their establishment. Once established they should not be used for vehicular access. Initial regular cutting (up to three times in the first year) should be followed by a programme of less frequent cutting (annually or every two years, at the end of the summer), with the aim of preventing woody growth. If necessary, the spread of undesirable species (for example, docks, thistles and ragwort *Senecio jacobaea*) should be controlled by spot herbicide treatment.

Extensive liaison and cooperation will be required with the landowners and/ or tenants when seeking to establish appropriate buffer strips.

Further information on the establishment of buffer strips

Natural England publications

- *Protecting water from agricultural run-off: an introduction* (TIN098) (http://publications.naturalengland.org.uk/publication/31002)
- *Protecting water from agricultural run-off: water retention measures* (TIN099) (http://publications.naturalengland.org.uk/publication/32002)
- *Protecting water from agricultural run-off: buffer strips* (TIN100) (http://publications.naturalengland.org.uk/publication/31003)
- *Farming for cleaner water and healthier soil* (NE230) (http://publications.naturalengland.org.uk/publication/36016?category=34002)
- *Farming in the uplands for cleaner water and healthier soil* (NE240) (http://publications.naturalengland.org.uk/publication/9031?category=34002)

Riparian woodland or scrub can also be very effective in reducing pollutant inputs to a watercourse. Allowing natural regeneration of riparian woodland is most likely to be successful, with deciduous native planting the next option. Note that the presence of tree cover along watercourses will introduce nutrients in the form of decaying leaf and root litter.

Further information on the establishment of riparian woodland or scrub buffer strips

- Forests and Water. UK Forestry Standard Guidelines (Forestry Commission 2011)
- *Riparian Vegetation Management* (SEPA 2009)

Benefits	Disadvantages
Buffer strips have a number of other benefits including helping to prevent soil erosion, stabilising banks, contributing to carbon retention, improving visual amenity and reducing costs for water treatment.	Benefits will take several years to be realised.
The benefits of buffer strips for biodiversity are significant, providing food, habitat and cover for a range of species and a network of interconnected habitats along which species can move.	Less effective on heavy or peaty soils.
	Land is taken out of agricultural production, or other uses.

Diffuse and point source pollution management

Other land management techniques, alongside buffer strips, can also help to reduce nutrient inputs to watercourses. For example temporary storage ponds, in-field grass areas and in-ditch wetlands, grassed waterways and seepage barriers all slow the path of potentially contaminated water to the watercourse.

Removing the source of the pollution through measures such as soil testing, precise crop management, considered placing of tramlines and the use of winter cover crops to prevent soil erosion can also all be helpful.

Management of discharges from point sources is also a good way of reducing pollutant inputs to watercourses. This approach will require partnership working with those organisations/ individuals responsible for such discharges. In addition, measures to treat point sources of pollution can include:

- tertiary treatment of waste water (to remove phosphate)
- tighter discharge consents upon industry

- channelling of road run-off through wetland treatment systems such as sustainable drainage systems (SUDS).

Benefits	**Disadvantages**
Other substances, not just nitrogen and phosphorous, may be removed leading to wider water quality benefits.	Benefits may take several years to be realised.
Aquatic organisms will benefit from improved water quality.	Can be expensive.
	Is likely to require cooperation with a wide range of organisations.

Nutrient-binding chemicals

Certain substances can be added into nutrient-enriched waters to artificially remove nutrients. These are known as nutrient-binding chemicals. For example, products containing naturally occurring lanthanum within a clay matrix are available that bind phosphorous. When applied to an aquatic environment the lanthanum binds with phosphate and results in a non-toxic mineral (rhabdophane) which becomes an inert component of in-channel sediments. This can help to lower phosphorous levels in nutrient-enriched waters. Tests have been conducted on these chemicals and no adverse impacts on aquatic organisms including fish, or water pH and oxygen levels, have been reported.

This technique is more applicable to lakes, ponds and reservoirs and is not usually applied to flowing waters, where there is a continual supply of phosphorus and the product is more readily dispersed.

Currently, there are no products available that bind nitrogen.

Benefits	**Disadvantages**
Relatively rapid reduction in phosphorous levels in comparison with other nutrient management techniques.	Expensive.
	Unsuitable for flowing watercourses.
	Not effective for nitrogen.

Key considerations

- **Partnership working –** to achieve the most benefits from buffer strips or the management of nutrients, it is important to liaise with landowners, tenants and other organisations.
- **Timescales –** the management of nutrient inputs to reduce the aquatic and riparian plant growth is a long-term management strategy; it may need to be used in conjunction with other techniques in the short term.
- **Environmental impact –**- the wider environmental benefits of nutrient management and pollution control should be considered and promoted.

7.6 Biological techniques

Biological control currently has limited use in aquatic plant management in UK watercourses and has been the subject of less research than other techniques. In appropriate circumstances, biological control methods can be cost-effective and can provide a longer-term solution. As most biological control measures tend to be much slower acting, and the level of control achieved difficult to predict, the greatest benefits may be gained when used in combination with other more short-term measures.

Current and historic forms of biological control for aquatic and riparian plants include:

- **Grazing** of banks by cattle, sheep and horses
- **Waterfowl**, in particular ducks, geese and swans, feeding on submerged aquatic plants and algae
- **Non-native grass carp** *Ctenopharyngodon idella* which feed on several species of submerged and floating aquatic plants
- **Native fish**, including carp *Cyprinus carpio* and bream *Abramis brama,* which disturb silt and cause turbidity, suppressing plant growth
- **Invertebrates** such as *Daphnia* spp. feeding on unicellular algae, and the Azolla weevil *Stenopelmus rufinasus*
- **Microorganisms** such as pathogenic bacteria and fungi which are known to attack aquatic plant species

Grazing by cattle, waterfowl, fish and invertebrates will reduce the abundance of vegetation, but their effects are unpredictable, difficult to control and could potentially be damaging to the wider environment. These are discussed further in the following sections and it is important to consider the impacts carefully before implementation.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Non-native grass carp ***Ctenopharyngodon idella***
© Jonathan Newman, Centre for Ecology and Hydrology

The introduction of non-native grass carp *Ctenopharyngodon idella* has been successfully used in the past to reduce plant growth within canals. A number of licences and consents are needed to release non-native grass carp *Ctenopharyngodon idella* and, under these, use of this technique would be restricted to enclosed water bodies where stocking densities can be controlled. As grass carp *Ctenopharyngodon idella* are a non-native invasive species that could escape into the wider environment, this technique is now not considered appropriate for the management of aquatic and riparian vegetation, and it is not discussed further within this guide.

Some invertebrates, such as the water flea (*Daphnia* spp.), feed on unicellular algae and can be quite effective in controlling algal blooms. Using invertebrates as a method of controlling algae often does not work because the invertebrates tend to be eaten by fish before they can have any real impact. The only way to attain the required numbers of invertebrates would be to remove fish, which is unlikely to be feasible in most watercourses.


Hydrocotyle weevils

© Jonathan Newman, Centre for Ecology and Hydrology

Research into the biological control of aquatic plant species has mostly focused on finding potential biological control agents to control invasive non-native species; insects of the weevil and leaf beetle families have been used most successfully. For example, the North American weevil *Stenopelmus rufinasus* was found to be one of the main natural enemies of water fern *Azolla* spp. and is now used successfully in the UK to control infestations of water fern (see section 7.6.4).

Current research is also examining the potential for biological control of invasive non-native species including Japanese knotweed *Fallopia japonica*, Australian swamp stonecrop *Crassula helmsii*, Himalayan balsam *Impatiens glandulifera* and floating pennywort *Hydrocotyle ranunculoides*. Potential control agents being investigated include stem mining flies, weevils and fungal species.

There are always concerns about the safety and effectiveness of introducing exotic species to control problem plant species. Extensive research, testing and monitoring are required prior to the approval for release of a species to ensure that non-target native plants or other species are not impacted.

7.6.1 Grazing of banks by cattle, sheep and horses


© Shire Group of IDBs

Summary: The control of aquatic and riparian vegetation, particularly on the banksides of watercourses, by grazing cattle, horses and sheep.

Cost: £

Medium-term option

Grazing by cattle, horses and sheep – and to a lesser extent goats – will control bankside vegetation, including non-native species, and also some emergent marginal plants such as grasses, reeds and rushes. If water is shallow enough, particularly in the summer, cattle and horses may also enter watercourses to graze on emergent and submerged plants.

However, the benefits gained through aquatic and riparian plant control may be outweighed by the damage caused to the banks due to poaching, and issues with erosion and siltation, particularly on smaller watercourses (less than 2 m wide) and/ or where stocking densities are high. The silt released through poaching can also increase the growth of aquatic or riparian plants, which can then cause problems due to raised nutrient levels. Increased erosion and siltation could also have implications for the achievement of WFD objectives due to impacts on hydromorphology.

Grazing could potentially have adverse impacts on protected species, for example, through the trampling of water vole *Arvicola amphibius* burrows and bird nests.

Limited access to watercourse banks and margins can produce benefits such as:

- selective grazing, which can lead to the creation of a varied structure of close-cropped and tussocky vegetation growth
- control of some marginal aquatic plants
- some limited poaching to produce muddy areas beneficial to wildlife


© JBA Consulting

Where grazing is already used to manage land adjacent to a watercourse, its implementation as an aquatic and riparian plant management technique can be relatively straightforward and cost-effective.

Benefits	Disadvantages
Effective control of bankside and some emergent vegetation.	Limited control of submerged or floating species.
Relatively cheap technique to implement.	Damage to banks due to poaching.
May provide habitat beneficial to wildlife.	Erosion and siltation issues due to poaching.
Conservation grazing could be used in some situations to bring wider environmental benefits.	Potential implications for the achievement of WFD objectives.
	Difficult to manage level of control.
	Potential for adverse impacts on protected species (for example, water vole *Arvicola amphibius* and breeding birds).
	Trampling by livestock can spread non-native invasive species.
	Not suitable for smaller watercourses.
	Some bankside plants may be toxic to animals (for example, hemlock water dropwort *Oenanthe crocata*).
	Nutrients from livestock directly enter watercourse.

Key considerations

- **Size of the watercourse –** the damage caused to the banks of the watercourse due to poaching is likely to outweigh the benefits gained through vegetation control on smaller watercourses (less than two metres wide).
- **WFD implications** – it will be necessary to carry out an assessment to determine whether grazing will result in hydromorphological impacts which could prevent the achievement of WFD objectives for the watercourse.
- **Presence of protected species** – if water voles *Arvicola amphibius* are present, it will be necessary to assess whether grazing could result in an offence under the Wildlife and Countryside 1981 (as amended) due to the trampling of burrows.
- **Stocking type and densities –** careful management of the number and type of stock used adjacent to watercourses will be required to ensure that the benefits in terms of vegetation management are realised while negative impacts are minimised.

Example: Grazing along the River Hooke, Dorset

The River Hooke, a tributary of the River Frome in Dorset, provides an excellent example of how grazing can be used to control non-native invasive bankside species, along with other riparian plants. The Return of the Natives (ROTN) Partnership secured funding to manage Himalayan balsam *Impatiens glanulifera* in the Frome catchment with the aim of reducing the seed sources upstream of the Frome SSSI. Due to the limited funding available, the partnership focuses much of its work on the River Hooke.

The first phase of the project was a scoping exercise to assess the distribution of Himalayan balsam *Impatiens glanulifera* and to provide management advice to landowners on how to reduce the prevalence of this plant. Where it was extensive, it was having a negative ecological impact by excluding native flora from bankside habitats, which in places included species-rich wet woodland and wet grassland areas, and also resulting in a loss of suitable bankside habitat for water voles.

Grazing is the traditional management of the wet grassland areas alongside the Hooke. Some sections of the river have been fenced to exclude all livestock access from the river, with the objective of improving water quality. Where fencing had been erected without any access points for temporary grazing, the project team noticed that there was an increased prevalence of Himalayan balsam along the river banks and associated habitats. The fencing also made further management of this species, through hand cutting or pulling, extremely difficult by limiting access.

This case highlights the potentially important role of grazing in managing some species, especially non-native invasive plants, and also the potential conflicts that may arise with the aims of other projects within a catchment. The benefits and potential adverse impacts of introducing fencing without access for livestock or other methods of management therefore need to be carefully assessed to meet the highest priority aims. Provided fencing continues to allow access for temporary grazing or other methods of control (such as mechanical or physical techniques), non-native invasive plant control can continue alongside other priorities for the site and catchment.

The photograph below illustrates how grazing has been beneficial at a site in Wiltshire.

7.6.2 Waterfowl

Summary: The control of submerged aquatic plants by grazing ducks, geese and swans.

Cost: £

Medium-term option

Ducks, geese and swans can consume large amounts of submerged aquatic plants. Ducks are very effective at controlling water-lilies as they have a particular preference for the buds and submerged leaves of these species. Swans, because of their large food requirement, are particularly successful at controlling vegetation, but as a pair of swans will defend a territory, the number of swans in any one place will generally be too low to have any significant impact on aquatic plant populations.

Control by waterfowl is only likely to be effective on small enclosed water bodies, such as ponds and small lakes, where numbers can be controlled. This technique is unlikely to be effective in isolation on watercourses, but could provide benefit in combination with other control measures.

Benefits	Disadvantages
Relatively cheap technique to implement.	Difficult to control number of waterfowl.
	Difficult to manage level of control.
	Droppings can cause potential water quality issues if large numbers of waterfowl present.
	Fragmentation by wildfowl can spread non-native invasive species.

Key considerations

- **Watercourse type** – control by waterfowl is only likely to be effective on small enclosed water bodies.

7.6.3 Native fish species

Summary: The control of submerged aquatic plants due to turbidity caused by native fish species.

Cost: £ or £££ if stocking of fish is required

Medium-term option

Native carp *Cyprinus carpio* and bream *Abramis brama,* and potentially other coarse fish, can act as a form of biological control by creating turbid water due to the disturbance of silt as they feed along the bottom of the channel. This reduces the penetration of light and suppresses plant growth. The high densities required to achieve control and the costs of management associated with this, plus the negative effects of turbidity, make this technique unlikely to be practicable in isolation on watercourses, but could provide benefits in combination with other measures.

Benefits	Disadvantages
Provides some control of submerged plants.	High densities of fish likely to be required.
Potential for recreational benefits for angling.	Adverse environmental impacts, including turbidity and nutrient enrichment.

Key considerations

- **Licensing and consents –** if fish are to be introduced, consent is needed from the Environment Agency under Section 30 of the Salmon and Freshwater Fisheries Act 1975 (as amended).
- **Environmental impacts –** potential adverse impacts including turbidity and nutrient enrichment will need to be considered.
- **Cost** – an expensive technique if stocking of fish is required.

7.6.4 Invertebrates – *Azolla* weevil

Summary: The release of a weevil to control water fern *Azolla filiculoides*.

Cost: ££

Short- to long-term option

Insects of the weevil and leaf beetle families have been used successfully as biological control agents of invasive non-native aquatic plants.

Within the UK, there is currently only one species of aquatic plant that can be controlled in this way – the invasive non-native water fern *Azolla filiculoides*.

Biological control of water fern

The North American weevil *Stenopelmus rufinasus* is a highly effective natural enemy of water fern *Azolla filiculoides*. They are able to control large quantities of water fern, sometimes within one growing season, without the need for chemicals or further control measures. The weevils can also be bred in large numbers for bulk release.

Water fern *Azolla filiculoides*
© Martin Redding, Witham Fourth District IDB

The weevil *Stenopelmus rufinasus* can only feed on *Azolla* species and therefore will not impact on native species. There are also no licensing restrictions as the weevil *Stenopelmus rufinasus* is already present in the UK (first recorded in 1921) and is therefore considered by Defra to be ordinarily resident.

The release of weevils *Stenopelmus rufinasus* is recommended early in the growing season before infestations of water fern *Azolla filiculoides* become too large, though they can be released at any time. Usually one release of the weevils is sufficient to provide control; however, more releases may be necessary for large infestations or where rapid control is required.

Weevils *Stenopelmus rufinasus* are currently available from CABI/ Azolla Control (www.azollacontrol.com).

Benefits	Disadvantages
Effective control of all sizes of infestation.	Relatively expensive application.
Easy technique to apply and maintain.	
Environmentally friendly technique which will benefit native submerged aquatic plants and animals.	
Should only require one release of weevils.	
Control, under ideal conditions, is rapid.	

Key considerations

- **Cost –** relatively expensive, particularly if needing to treat a large infestation. However, the technique provides effective control and has a number of advantages over other methods.

Example: Use of weevils to control water fern in the Witham Fourth IDB district

In 2012, many watercourses in Lincolnshire and elsewhere around the country suffered from dense infestations of water fern *Azolla filiculoides*, including several within the Witham Fourth drainage district. Consequently, a number of batches of the North American weevil *Stenopelmus rufinasus* were released. The dense infestations recorded in 2012 within the drainage districts have not reappeared in 2013.


© Martin Redding, Witham Fourth IDB


© Martin Redding, Witham Fourth IDB

7.7 Novel techniques

Over recent years there have been a number of innovations in the field of aquatic and riparian plant management. While these have not yet become widely used to manage problematic plant species within watercourses, they may become more viable options in the future as the technology develops and costs decrease. As these techniques are relatively new and require emerging technologies, they are generally considered to be very expensive. The exception is ultrasound, which can be relatively cost-effective.

7.7.1 Hot foam

This technique uses an innovative treatment that works by combining hot water and steam with a naturally sourced foaming agent (for example, oil seed rape and sugars from potato, wheat and maize) to generate hot foam that covers the problem species in a thermal blanket, thereby rupturing their cell structure. Being derived from natural substances, this technique is considered to be relatively safe and environmentally friendly, although its persistence in water is currently uncertain.

The technique uses a tractor-mounted delivery system and therefore its use in purely aquatic environments is limited. A watercourse may require draining down prior to treatment, although it may have some application in marginal areas.

The use of hot foam has been extensively trialled on Australian swamp stonecrop in the New Forest and at sites in Norfolk. While initial results appeared promising, long-term success is currently uncertain as it appears that the technique did not kill off the roots and it has regrown at all sites. Its applicability for use on other emergent and riparian species is currently unknown.

It is a non-selective technique that impacts on all species treated with the foam. Careful application can reduce impacts on non-target species.

Example: Hot foam trials in the New Forest

In September 2011, the Hampshire and Isle of Wight Wildlife Trust trialled the use of hot foam to treat infestations of Australian swamp stonecrop *Crassula helmsii* at a number of sites in the New Forest, including a pond at Abbot's Well, near Frogham, and on Beaulieu Heath. The trial is due to last until 2014, although the wet conditions in 2012 meant that the hot foam treatment could not be carried out that year.

Initial results suggest that the decline in Australian swamp stonecrop cover following treatment was not significant, with only a 12% reduction in cover reported (Ewald 2013), though the wet year in 2012 may have impacted on this. The study has shown that dry conditions are necessary for this treatment, but the full results of the trial and its effectiveness for this species is not yet known.


© Catherine Chatters, Hampshire and Isle of Wight Wildlife Trust


© Catherine Chatters, Hampshire and Isle of Wight Wildlife Trust

7.7.2 Ultrasound

Ultrasound technology has been developed for treating algae in ponds and watercourses. It cannot be used for any other groups of problematic aquatic and riparian plant species. The technique offers the benefits of a non-chemical, targeted control and a range of equipment is available to implement it. It is effective against both filamentous and unicellular green algae/ cyanobacteria.

Ultrasound works by transmitting sound frequencies between 25 and 99 kHz to the water. The sound waves interact with algal cells and algal cell membranes resulting in a number of effects. In cyanobacteria, but not other species, this technique destroys those parts of the cell that regulate buoyancy, making them sink out of suspension. In other types of algae, the impact of ultrasound is less clear, but a range of responses are seen including loss of membrane integrity, shrinkage of cell contents, loss of buoyancy and cell necrosis (death).

Example: Impact of ultrasound on filamentous green algae *Spirogyra* up to 21 days after exposure

Day 0 | Day 14 | Day 21

Images © NERC with permission

None of the effects appear on other organisms such as higher plants, including duckweed *Lemnaceae,* stoneworts, fish or motile invertebrates.

Motile algae are also less susceptible to ultrasound, as are the majority of diatoms. Diatoms are normally useful algae in that, when they fall out of suspension at the end of an algal bloom, they take a lot of phosphate to the sediment where it is unavailable to other algae. This has the beneficial effect of lowering phosphorous concentrations in some water bodies.

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Ultrasound transducer

Other beneficial effects of ultrasound include an increase in hatching rate of fish eggs due to an increase in the permeability of egg membranes to dissolved oxygen, and an increased survival rate of juvenile fish (Xie et al*.* 1992). There have been no observed effects on non-target organisms including crustaceans (*Daphnia* spp.*, Gammarids),* caddisflies *Trichoptera* spp., goldfish *Carassius auratus*, rainbow trout *Oncorhynchis mykiss*, frogs, newts, toads, bats or birds.

There are several systems available that operate from either 240 volts AC or are solar powered for remote installation operating at 24 volts DC. The effective range is from less than 10 m to over 400 m for some systems. More advanced systems offer remote management.

This technique has the additional benefit of being relatively cheap to implement.

7.7.3 Electromagnetic water treatment

Electromagnetic water treatment is currently being developed for the treatment of extensive algal infestations in water, including filamentous green algae. Magnetism has been used to inhibit the growth of the alga *Cladophora glomerata* in laboratory conditions and systems are now available for purchase to treat algae in ponds and watercourses.

These electromagnetic water treatment systems transmit dissonant resonant frequencies of undesired molecules such as nitrates and phosphates, and their concentration declines, removing the key nutrients responsible for algal blooms (and other aquatic plant problems), thereby reducing the algae problem. Such systems may be useful in combating algal growths in watercourses, but further assessment and development is needed before they can be installed.

7.7.4 Suction techniques

A number of relatively novel techniques are available which involve using specialist suction machines to treat aquatic plant problems. This includes suction harvesting of free-floating species from the surface of watercourses, diver-operated suction harvesting of submerged species and Hydro Venturi.

Suction harvesting techniques can be implemented for species free-floating on the water surface (that is, duckweeds *Lemanceae* and water fern *Azolla filiculoides*). The technique involves vacuum suctioning apparatus that can be targeted at areas with dense coverage of these species.

Diver-operated suction harvesting involves deploying divers into a watercourse with a small device to select and remove individual plants or small stands from the bed of a watercourse. This technique mobilises significant quantities of silt from the watercourse bed and increases turbidity. It is also a very slow technique (approximately 100 m^2 can be treated per diver per day) and very expensive, requiring specialist training and equipment. Collected plant material also requires disposal off-site. Its applicability in watercourses in the UK is also likely to be quite limited and is likely to be only used in relation to non-native invasive species.

The Hydro Venturi technique has been developed in the Netherlands, primarily for the control of non-native invasive species as the use of herbicides is not permitted in water there. The technique uses a specially developed injection device, based on a boat, which injects an air and water mixture into the sediment. This washes the roots of the plant out of the sediment and the plant material floats to the surface where it can be collected, thereby avoiding fragmentation. This technology, when used correctly, can remove 95–100% of a plant infestation from a water body; however, this often requires accurate pre- and post-treatment surveys to ensure that no plant material remains from which recolonisation could occur. It is a non-selective technique which can also remove native species from the sediment. It is also a slow and expensive, but thorough process, and may be best suited to situations where permanent removal of the vegetation is vital and the site can be protected against recolonisation from sources upstream or nearby.

7.7.5 Infrared

This technique exposes plants to a stream of radiated heat to control them and has been widely used in countries such as the Netherlands. It could be suitable in some locations in the UK where disturbance of soil is not an option. Larger versions of this technology are non-selective and so are unsuitable for controlling individual plants. There is also limited penetration below ground and regrowth may occur from deep-rooted species. Its applicability in the aquatic and riparian environment is also limited.

7.8 Integrated management

All aquatic and riparian plant management techniques have positive and negative aspects, and no management technique is intrinsically superior to another. In some watercourse types and with certain species, or combinations of species, a single management technique may not be appropriate. In these instances an integrated approach is often the best way of undertaking management.

For example, the cutting of submerged plants can be extremely difficult if they are entangled with large masses of filamentous algae. In this instance, an integrated management approach would be useful, for example, using barley straw or barley straw extract to control the algae, which would increase the efficacy and reduce the frequency of cutting required to manage the submerged species.

The management of non-native invasive species also often necessitates the use of integrated techniques as they can be very aggressive colonisers and extremely difficult to control.

For example, the mechanical treatment of extensive stands of floating pennywort *Hydrocotyle ranunculoides* is often advised to reduce the biomass present in the watercourse, followed by a secondary technique such as the application of glyphosate-based herbicide or hand pulling to ensure all fragments created from the mechanical technique are removed.

Similarly, a combination of environmental and chemical techniques (that is, manipulation of water levels through temporary draining down and then application of a glyphosate-based herbicide) is one of the most effective methods for the management of Australian swamp stonecrop *Crassula helmsii*.

8. Decision-making spreadsheet tool

8.1 Introduction

To assist selection of the most appropriate technique(s) for the particular species problem faced and the type of watercourse where management is required, a spreadsheet tool has been developed to provide a framework for decision-making. This is available on the Environment Agency's website.

The decision-making spreadsheet tool has three elements:

- an assessment of the effectiveness of each technique in managing a **species**
- an assessment of the potential impact of each technique on different **watercourse types**
- an appraisal of the **technical feasibility** (for example, channel width, water depth, watercourse length) of each technique

Full details on how the decision-making spreadsheet tool works and was developed are provided in Appendix D.

This technical guide is accompanied by a field guide for use when collecting the information on-site that is needed to use the decision-making spreadsheet tool and select the most appropriate management technique.

8.2 How to use the spreadsheet tool

8.2.1 Stage 1 – Audit trail

The first stage of the spreadsheet tool involves recording basic data on the watercourse to be managed (Figure 8.1) including:

- watercourse name and location
- WFD reference number
- start and end grid references of the reach to be managed
- author
- date

This will provide an audit trail that can be retained for future reference or to demonstrate the process that has been followed when selecting management of a watercourse.

Additionally, a series of questions are asked about whether the watercourse is within or adjacent to a designated nature conservation site, and whether protected species are present. Guidance is then given on what action to take should a designated site or protected species be present. Where this information is unknown, details are given of sources where this information can be obtained.

For watercourses within or adjacent to a designated nature conservation site, a management plan may already be in place and the use of the decision-making spreadsheet tool may not be appropriate.

Watercourse Name
Holderness Drain
Location
Leven

Is the watercourse a designated site or is it adjacent to a designated site? No

WFD Watercourse number GB104026066950
Start Grid Reference TA084477
End Grid Reference TA097450

Does the watercourse support populations of protected species (e.g. water vole, otter, white-clawed crayfish)? Yes

Contact Natural England/ Natural Resources Wales/ Environment Agency for further advice and follow appropriate species guidance. See section 4.4.2 of the Technical Guide.

Prepared by Peter Robinson
Date 20/11/2013

Figure 8.1 Screenshot of stage 1 of the decision-making spreadsheet tool

8.2.2 Stage 2 – Watercourse type, problem species and technical parameters

The next stage involves inputting a range of information on the watercourse itself and the problem species/ group of species. The following information is required.

- **Select species.** A drop-down list of the main problematic aquatic and riparian plants (as detailed in Chapter 5) is provided from which the problem species can be selected. Every attempt should be made to identify the problem species. Where the problem species is not known, a species group (submerged, free-floating, rooted floating-leaved, broad-leaved emergent and tall emergent) can be selected; these groups are listed after the specific species.
- **Select watercourse type.** A drop-down list of the geomorphic watercourse type (as detailed in Chapter 6) is provided.
- **Length of watercourse to be maintained (m).** This should be the length of the reach to be maintained, not necessarily the full length of the watercourse.
- **Channel width (m).** This parameter relates to the width of the watercourse at water level (that is, wetted width). Where the channel width is variable, the minimum width should be inputted.
- **Water depth (m).** Where water depth varies, the minimum depth should be inputted.
- **Access**. Two questions are asked. First whether access with a machine, such as a tractor or excavator, is possible, and secondly whether boat access is possible.

Select Species
Branched bur-reed Sparganium erectum

Data must be entered into all the white cells in this section before any recommendations can be made

Select Watercourse Type
Artificial Drainage Channel

Length of watercourse to be managed (m) 2800
Channel width (m) (ie wetted width) 2.5
Water depth (m) 0.5

Machine access possible? Yes
Boat access possible? No

Notes for selected species:
Tall emergent species are often very important in stabilising the toes of banks and management should aim to ensure that a protective fringe of tall emergent vegetation is retained.
Tall emergent species can often provide nesting sites for a range of bird species; management of large stands of tall emergent species should always be conducted outside of the bird breeding season (March-September).

Figure 8.2 Screenshot of stage 2 of the decision-making spreadsheet tool

8.2.3 Outputs

The possible management techniques based on the data inputted are returned as a series of ranked options. The most appropriate technique, based on its effectiveness to control the given species and the potential damage to a specific type of watercourse, is given the highest score. The score will range from 0 to 3; the higher the score, the more appropriate the technique is considered. Where techniques are returned with the same score, they are given equal rankings. Figure 8.3 shows an example of the ranked options.

Other information is also returned alongside the list of rank techniques, including the scores given for effectiveness of control and damage to watercourse type, so that an informed decision can be made on which technique to select.

An indication of the relative cost of the technique, either low (£), medium (££) or high (£££), is also provided. Although direct monetary comparisons of the different techniques are not possible given the number of variables being considered, indicative, relative costs are provided to allow watercourse managers to compare individual techniques.

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1=	Glyphosate-based herbicide	7.4.1	lance	3	0.17	1	2.50	£
1=	Glyphosate-based herbicide with adjuvant	7.4.1	lance	3	0.17	1	2.50	£
3	Hand cutting	7.3.1		2	0.00	1	2.00	£££
4	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.33	1	1.33	££
5=	Buffer Strips	7.5.6		1	0.17	1	0.83	££
5=	Diffuse and point source pollution management	7.5.6		1	0.17	1	0.83	£££
5=	Excavator and tractor mounted cutter/flail	7.3.5		1	0.17	1	0.83	£
5=	Hand pulling	7.3.1		1	0.17	1	0.83	£££ / £ (*)
9=	Channel narrowing to increase velocity (two-stage channel)	7.5.5		1	0.33	1	0.67	£££
9=	De-weeding with a weed bucket	7.3.3		2	0.67	1	0.67	££
11=	De-weeding with a solid bucket	7.3.4		2	0.83	1	0.33	£££
11=	Grazing of banks by cattle, sheep and horses	7.6.1		2	0.83	1	0.33	£

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)   The maximum possible score is 3   (*) = lower cost if use volunteers

Figure 8.3 Example output from the decision-making spreadsheet tool

From this ranked list of possible options, the watercourse manager can then select the most suitable technique for their specific site, bearing in mind the following.

- Based on site-specific factors, the top-ranked option may not be appropriate; it is acceptable to select lower ranked options and this should be informed by the scores provided.
- It may be that two or more of the given techniques may be employed, given site specific factors.

The tool provides a list of possible techniques to help inform how a watercourse is managed. **The watercourse manager must always use their own judgement and site-specific knowledge when selecting a technique.**

For example, in urban situations the applicability of some techniques is likely to be limited. For example, grazing is unsuitable along most urban watercourses and shading with materials is potentially inadvisable due to the risk of vandalism and damage. Consequently, an option must be selected from the returned list of possibilities based on site-specific knowledge.

The spreadsheet tool is able to return up to 12 possible techniques to select from. In some instances, fewer than 12 techniques will be returned. This is because the other possible techniques are considered ineffective, technically unfeasible or too damaging and therefore inappropriate.

The output will print out on one page so that it can be kept as part of an audit trail or incorporated into a site management plan.

Figure 8.4 provides a summary of the process of using the decision-making spreadsheet tool with links to the flowchart shown in Figure 4.1 summarising the procedure for planning management of aquatic and riparian vegetation.

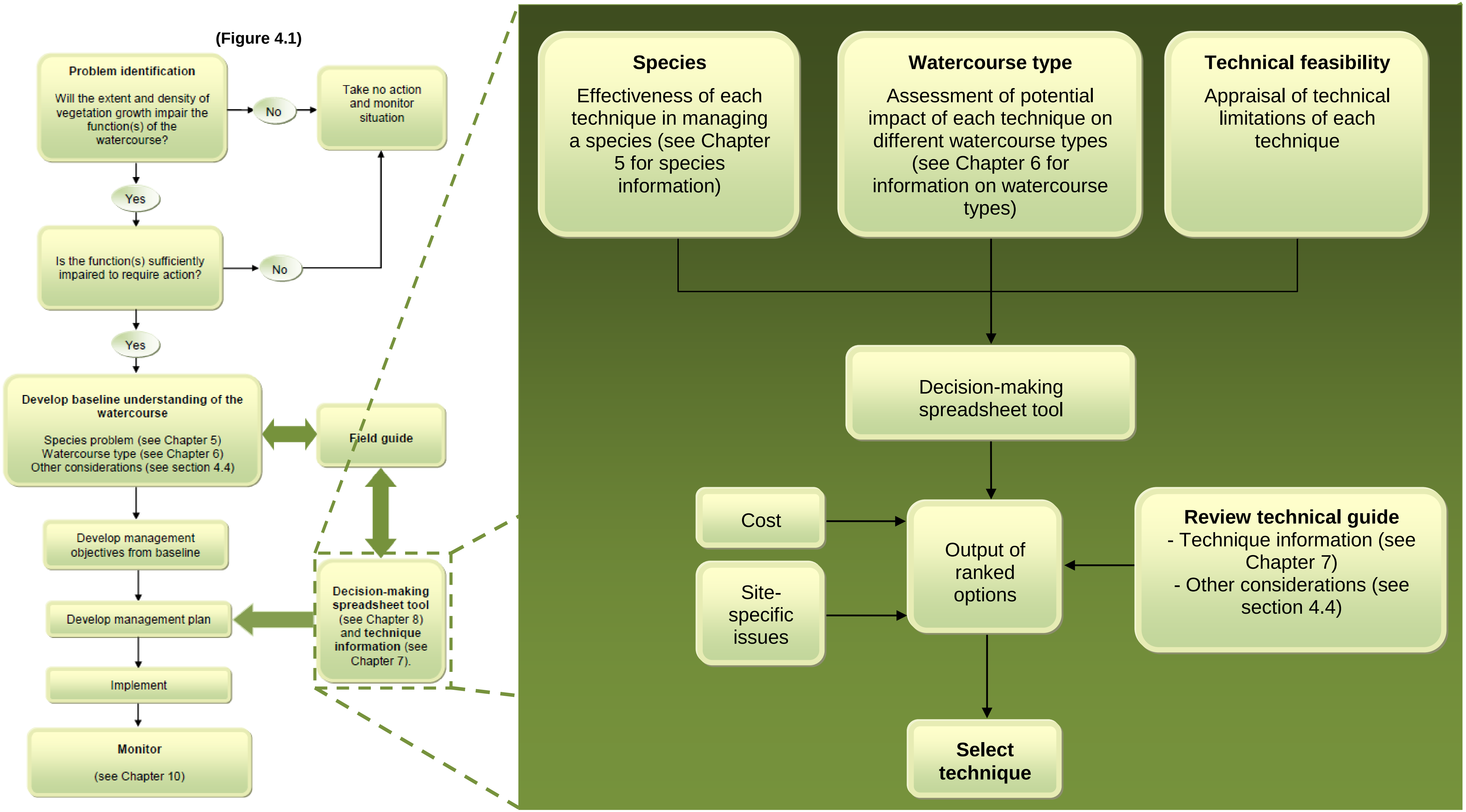

Figure 8.4 Summary of decision-making spreadsheet tool process, with links to Figure 4.1

8.2.4 Management of long watercourses

In many instances watercourses several kilometres long will require management. It is unlikely that the same plant species, or group of species, will be problematic along the full length and the species that is problematic is likely to change along the length of the watercourse. In this instance the watercourse should be broken down into management reaches, with the tool run independently for each reach. The results of then be used to select the management technique, or number of techniques, as most appropriate.

It may be the case that a single management technique can be selected for the entire watercourse as it is returned as a feasible option for several reaches, either as the top ranked option, or within the top few options.

Example: North Idle Drain, North Lincolnshire

North Idle Drain is a long straight watercourse, with different problematic species occurring in different sections. Some sections are dominated by common reed *Phragmites australis*, whereas others are completely dominated by branched bur-reed *Sparganium erectum* or broad-leaved pondweed *Potamogetons natans*. Management of the watercourse is required for land drainage and flood risk purposes and to ensure that the notable aquatic vegetation for which the SSSI is designated is not out-competed by these dominant species.

In this example the spreadsheet tool is run three times, once for each species. The first step is to enter standard information for the entire reach to be maintained such as watercourse name, width, water depth and designated status. On each of the three separate runs, the varying parameters are changed as follows:

- Reach 1 – common reed dominant over 965 m
- Reach 2 – branched bur-reed dominant over 775 m
- Reach 3 – broad-leaved pondweed dominant over 865 m

The outputs are then compared as shown in the table below. The colour coding applied by the spreadsheet based on the effectiveness and potential damage scores combined is also shown.

Technique	Reach 1 Common reed	Reach 2 Branched bur-reed	Reach 3 Broad-leaved pondweed
Glyphosate-based herbicide	1=	1	4=
Glyphosate-based herbicide with adjuvant	1=	1=	1
Hand cutting	3	3	3
Channel narrowing to increase velocity (two-stage channel)	4	9=	
Buffer strips	5=	5=	4=
Diffuse and point source pollution management	5=	5=	4=
Excavator and tractor mounted cutter/flail	5=	5=	
De-weeding with a weed bucket	8	9=	8
De-weeding with a solid bucket	9=	11=	9=
Grazing of banks by cattle, sheep and horses	9=	11=	
Shading through tree/hedgerow/bankside planting		4	2
Hand pulling		5=	4=
Hand raking			9=

In this case, the most effective technique for all three problem species within this watercourse would be treatment using a **glyphosate-based herbicide with an adjuvant**.

8.2.5 Management of watercourses with multiple species problems

In some instances more than one species may be considered to be a problem. The spreadsheet tool only allows for one species to be inputted. Where more than one species is considered to be problematic, the spreadsheet should be run for each species. The returned techniques are then assessed, with the most frequently returned or common technique applied.

The case studies of the Moretons Leam in Cambridge and the River Lee in Luton detailed in sections 9.1 and 9.2 respectively provide examples of how to do this.

9. Case studies

This chapter describes the use of the spreadsheet tool to support decisions on aquatic and riparian plant management at five case study sites. The sites are:

- River Mole, Surrey
- Nafferton Beck, East Yorkshire
- Moretons Leam, Cambridgeshire
- River Lee, Luton
- Boating Dike, South Yorkshire

The case study sites were selected to cover a variety of aspects and issues including different species, watercourse types, management techniques, operating authorities and geographical locations. Their location is shown in Figure 9.1.

Figure 9.1 Location of case study sites

Short summaries of the case studies are given below. More details of the five sites and their selection are given in the accompanying case study report.

9.1 River Mole, Surrey

The River Mole, a tributary of the Thames, flows from its headwaters near Crawley to where it connects to the Thames at East Molesley, in the borough of Elmbridge, south-west London. The section of concern is the downstream reach, from the Island Barn Reservoir to the confluence with the Thames, a length of approximately 3.5 km.

This reach is heavily modified and land use is predominantly urban and suburban development with numerous gardens backing on to the river. There are also numerous weirs, sluices and bridges within this section.

Problem species

The non-native invasive species floating pennywort *Hydrocotyle ranunculoides* is a major problem. This species is listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended).

Historical management

Floating pennywort has been problematic on this stretch of river for 13 years. Many, predominantly physical, approaches to controlling it have been tried including weed boats and long-reach excavators, but the level of fragmentation with these techniques and the potential for downstream spread was considered to be to too high. Hand pulling from a boat or using operatives in waders was trialled, but was found to be time-consuming and onerous.


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Booms have been regularly used to collect waste material, which was then loaded into tug boats for disposal off-site, but this was expensive. Now the approach is to leave the waste material on the bank where possible to decompose naturally.

By 2013 the management conducted was showing considerable success with few areas of infestation remaining. Where it was found it was only in small, localised patches, interspersed within stands of other species (generally branched bur-reed *Sparganium erectum*) and beneath structures that protruded into the river, such as decking.

Management has been achieved through a combination of:

- localised glyphosate-based herbicide application
- hand pulling and cutting

A regular monitoring and early intervention approach is adopted to prevent infestations becoming too extensive. This involves operatives routinely monitoring the river from a boat, and hand pulling or cutting any small patches found.

Canopy raising, which involves trimming and cutting back of overhanging branches and vegetation, was also found to be effective to prevent establishment of this species. Where there are overhanging branches it is very easy for floating pennywort to become entangled and for infestations to develop.

The need for management

Control of floating pennywort *Hydrocotyle ranunculoides* is carried out primarily for flood risk management purposes as the large rafts can block structures, having a localised impact.

The **objectives** for the management of the River Mole are to:

- control the extensive infestation of floating pennywort *Hydrocotyle ranunculoides*
- ensure weirs and other structures do not become blocked


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Using the spreadsheet tool

Table 9.1 summarises the data inputs to the spreadsheet tool.

Table 9.1 Data inputs to spreadsheet tool for River Mole

Parameter	Input
Is the watercourse a designated site or is it adjacent to a designated site?	No
Does the watercourse support populations of protected species (for example, water vole, otter, white-clawed crayfish)?	No
Problem species	Floating pennywort *Hydrocotyle ranunculoides*
Watercourse type	Modified urban watercourse
Length of watercourse to be managed (m)	3,500 m
Channel width (m) (that is, wetted width)	10–15 m (minimum of 10 m inputted)
Water depth (m)	Water levels are variable. They are very shallow (less than 0.5 m) in some places, becoming deeper downstream (over 1 m in places) (minimum of 0.5 m inputted)
Machine access possible?	Yes
Boat access possible?	Yes

The output is shown in Figure 9.2. The highest ranked option returned is glyphosate-based herbicide with adjuvant, applied by either a boat or lance, followed by hand cutting and hand pulling. This supports the approach currently being implemented at this location.

As a longer-term strategy, increasing shading through additional tree planting on the river banks could be considered (output rank 4). However, site-specific issues including the high number of private residences and landowners that back onto the river could make this difficult to implement.

Confirming the findings of previous management operations at this site, which resulted in fragmentation, use of a weed boat or de-weeding with a weed bucket are much lower ranked options.

Watercourse Name
River Mole
Location
East Molesley, Surrey

Is the watercourse a designated site or is it adjacent to a designated site? No

WFD Watercourse number GB106039017622
Start Grid Reference TQ14346756
End Grid Reference TA15266817

Does the watercourse support populations of protected species (e.g. water vole, otter, white-clawed crayfish)? No

Prepared by Laura Thomas
Date 16/12/2013

Select Species
Floating pennywort Hydrocotyle ranunculoides

Data must be entered into all the white cells in this section before any recommendations can be made

Select Watercourse Type
Modified Urban Watercourse

Length of watercourse to be managed (m) 3500
Channel width (m) (ie wetted width) 10
Water depth (m) 0.5

Machine access possible? Yes
Boat access possible? Yes

Notes for selected species:
Floating pennywort is a non-native invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended); it is an offence to plant or cause its spread in the wild.
Physical control techniques should be implemented with care; fragmentation can result in spread.

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1=	Glyphosate-based herbicide with adjuvant	7.4.1	boat	3	0.06	1	2.83	£
1=	Glyphosate-based herbicide with adjuvant	7.4.1	lance	3	0.06	1	2.83	£
3	Hand cutting	7.3.1		2	0.00	1	2.00	£££
4	Hand pulling	7.3.1		2	0.06	1	1.89	£££ / £ (*)
5	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.11	1	1.78	££
6=	Glyphosate-based herbicide	7.4.1	boat	1	0.06	1	0.94	£
6=	Glyphosate-based herbicide	7.4.1	lance	1	0.06	1	0.94	£
6=	Weed boats	7.3.2		1	0.06	1	0.94	£
9=	Channel narrowing to increase velocity (two-stage channel)	7.5.5		1	0.11	1	0.89	£££
9=	Mechanical harvesters	7.3.2		1	0.11	1	0.89	££
11	Amphibious vehicles	7.3.2		1	0.17	1	0.83	£
12	De-weeding with a weed bucket	7.3.3		1	0.22	1	0.78	££

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)   The maximum possible score is 3   (*) = lower cost if use volunteers

Figure 9.2 Screenshot of output from spreadsheet tool for River Mole, Surrey

9.2 Nafferton Beck, East Yorkshire

Nafferton Beck is located to the east of Driffield, East Yorkshire. It flows south from the village of Nafferton to Driffield Canal.

It is a wide (approximately 4–5 m), shallow, slow-flowing watercourse, with relatively low banks (approximately 1–1.3 m in height). The substrate is predominantly gravels with some silt.

Adjacent land use consists predominantly of arable fields. An intermittent hedgerow with some large, mature trees is present along the right bank. A public footpath is present along the top of the left bank.

Problem species

The main problem species is emergent branched bur-reed *Sparganium erectum*, which grows throughout the channel and, in places, covers the full width.

Other tall emergent species present include reed canary-grass *Phalaris arundinacea* and common reed *Phragmites australis* along the bank margins and on the banks.

The need for management

Land drainage and flood risk management are the primary drivers of watercourse maintenance. Tall emergent species can impede the flow of flood waters and cause the accumulation of debris.

> The **objective** for the management of Nafferton Beck is to:
>
> - ensure adequate conveyance of water through the management of tall emergent vegetation

Using the spreadsheet tool

Table 9.2 summarises the data inputs to the spreadsheet tool.

Table 9.2 Data inputs to spreadsheet tool for Nafferton Beck

Parameter	Input
Is the watercourse a designated site or is it adjacent to a designated site?	No
Does the watercourse support populations of protected species (for example, water vole, otter, white-clawed crayfish)?	Yes – water vole *Arvicola amphibius* are present
Problem species	Branched bur-reed *Sparganium erectum*
Watercourse type	Artificial drainage channel
Length of watercourse to be managed (m)	525 m
Channel width (m) (that is, wetted width)	4–5 m (minimum of 4 m inputted)
Water depth (m)	Water depth varies but consistently shallow (0.2 m inputted)
Machine access possible?	Yes
Boat access possible?	Yes

The output is shown in Figure 9.3. The highest ranked options returned are glyphosate-based herbicide and glyphosate-based herbicide with adjuvant. This supports the approach currently being implemented at this location. Hand cutting is also a highly ranked option but due to the relatively high cost of this technique it may not be feasible.

As a longer-term strategy, increasing shading through additional tree planting on the banks of the beck could be considered (output rank 4).

Watercourse Name

Nafferton Beck

Location

Nafferton, East Yorkshire

Is the watercourse a designated site or is it adjacent to a designated site? No

WFD Watercourse number: GB104026067090
Start Grid Reference: TA06525669
End Grid Reference: TA06515722

Does the watercourse support populations of protected species (eg Water Vole, Otter, White-clawed Crayfish)? Yes

Contact Natural England/Natural Resources Wales/Environment Agency for further advice and follow appropriate species guidance. See section 4.5.2 of the Technical Guide.

Prepared by: Rachael Brady
Date: 20/11/2013

Select Species

Data must be entered into all the white cells in this section before any recommendations can be made

Branched Bur-reed Sparganium erectum

Select Watercourse Type

Artificial Drainage Channel

Length of watercourse to be managed (m): 575
Channel width (m) (ie wetted width): 4
Water depth (m): 0.1

Machine access possible? Yes

Boat access possible? Yes

Notes for selected species:

Tall emergent species are often very important in stabilising the toes of banks and management should aim to ensure that a protective fringe of tall emergent vegetation is retained.
Tall emergent species can often provide nesting sites for a range of bird species; management of large stands of tall emergent species should always be conducted outside of the bird breeding season (March-September).

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1=	Glyphosate-based herbicide	7.4.1	lance	3	0.17	1	2.50	£
1=	Glyphosate-based herbicide with adjuvant	7.4.1	lance	3	0.17	1	2.50	£
3	Hand cutting	7.3.1		2	0.00	1	2.00	£££
4	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.33	1	1.33	££
5	Amphibious vehicles	7.3.2		2	0.50	1	1.00	£
6=	Buffer Strips	7.5.6		1	0.17	1	0.83	££
6=	Diffuse and point source pollution management	7.5.6		1	0.17	1	0.83	£££
6=	Excavator and tractor mounted cutter/flail	7.3.5		1	0.17	1	0.83	£
6=	Hand pulling	7.3.1		1	0.17	1	0.83	£££ / £ (*)
10=	Channel narrowing to increase velocity (two-stage channel)	7.5.5		1	0.33	1	0.67	£££
10=	De-weeding with a weed bucket	7.3.3		2	0.67	1	0.67	££
12=	De-weeding with a solid bucket	7.3.4		2	0.83	1	0.33	£££

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)   The maximum possible score is 3   (*) = lower cost if use volunteers

Figure 9.3 Screenshot of output from spreadsheet tool for Nafferton Beck

9.3 Moretons Leam, Cambridgeshire

Moretons Leam is an artificial drainage channel approximately 20 km in length, located in Cambridgeshire. It flows from the outskirts of Peterborough to the sluice at Guyhirn where it discharges into the River Nene. There are numerous control structures along its length and the channel is trapezoidal.

Adjacent land use is predominantly cattle-grazed improved/ semi-improved pasture which forms the Nene Washes.

Problem species

The central part of the channel is relatively deep and dominated by:

- filamentous green algae
- floating-leaved rooted species including yellow water-lily *Nuphar lutea*
- submerged species including perfoliate pondweed *Potamogeton perfoliatus* and fennel pondweed *P. pectinatus*

The margins are frequently lined with a narrow fringe of tall emergent species, including branched bur-reed *Sparganium erectum*, reed sweet-grass *Glyceria maxima* and greater pond-sedge *Carex riparia*. These species do not encroach into the centre of the channel and therefore do not require management.

The need for management

Moretons Leam is a critical part of the water level management system of the area as it is the only means of getting water off the Nene Washes following a flood event. Good conveyance of water is required to do this. During a flood event, urban areas such as

Whittlesey are also potentially at risk of flooding should further rain fall and the Nene Washes are already inundated to capacity.

Management of water is also required for the ecological interests of the Nene Washes. The level of water and the timing, depth and duration of flooding are critical for many species and also for the cattle grazing regime. In previous years excessive vegetation growth in the watercourse during the summer months has impacted on water levels on the Nene Washes and has had a detrimental impact on nesting birds. During dry periods, water from the River Nene is also let onto the washes to maintain the ecological interests.

The **objectives** for the management of Moretons Leam are to:

- ensure conveyance is maintained for flood risk management and land drainage purposes
- maintain the ecological interests of Moretons Leam and the Nene Washes (for example, wading and wetland birds)

Using the spreadsheet tool

Table 9.3 summarises the data inputs to the spreadsheet tool.

Table 9.3 Data inputs to spreadsheet tool for Moretons Leam

Parameter	Input
Is the watercourse a designated site or is it adjacent to a designated site?	Yes – Moretons Leam is designated as part of the Nene Washes Ramsar site, SPA, SAC and SSSI
Does the watercourse support populations of protected species (for example, water vole, otter, white-clawed crayfish)?	Yes – the watercourse contains the highest recorded density of spined loach *Cobitis taenia* in the UK
Problem species	Yellow water-lily *Nuphar lutea* Submerged pondweeds *Potamogeton* spp. Filamentous green algae
Watercourse type	Artificial drainage channel
Length of watercourse to be managed (m)	4,700 m. The section visited stretches from Little Bridge to Eldernell.
Channel width (m) (that is, wetted width)	Channel width varies from 4–5 m (minimum value of 4 m inputted)
Water depth (m)	Water depth varied from 1.5 to 2 m (minimum value of 1.5 m inputted)
Machine access possible?	Yes
Boat access possible?	Yes

As the site contains multiple problem species, the spreadsheet tool was run three times, once for each species. The outputs are compared in Table 9.4. The output for submerged pondweeds is shown in Figure 9.4.

Table 9.4 Data outputs for three problem species at Moretons Leam

Technique	Yellow water-lily	Submerged pondweeds	Filamentous green algae
Glyphosate-based herbicide with adjuvant (boat and lance application)	1=		
Waterfowl	3		
Glyphosate-based herbicide (boat and lance application)	4=		
Weed boats	4=	2	5=
Channel narrowing to increase velocity (two-stage channel)	7=		
Shading through tree/ hedgerow/ bankside planting	7=	3	3
Amphibious vehicles	9=	4=	8=
Hand cutting	9=	4=	
Buffer strips	11=	7=	5=
Diffuse and point source pollution management	11=	7=	5=
Shading with native, broad-leaved floating species		1	2
Native fish species		4=	4
Hand pulling		7=	
De-weeding with a weed bucket		10	10
Hand raking		11=	8=
De-weeding with a solid bucket		11=	
Barley straw extract			1

Given the complexity of this site, including the multiple problem spices, designated status, rare fauna and current open landscape, a site-specific analysis was then applied to the list of techniques. This site-specific analysis concluded that:

- glyphosate-based herbicide application, with and without an adjuvant, would not be permitted by Natural England within this designated site
- shading through tree/ hedgerow/ bankside planting would create predator perches which would threaten the wading bird interest of the Nene Washes and is not advised
- waterfowl, channel narrowing to increase velocity (two-stage channel), native fish species, hand pulling, de-weeding with a solid bucket and barley straw extract are not advised as they would only be effective in managing one of the three problem species
- manipulation of the native fish populations should not be undertaken given the presence of the rare spined loach

Although hand cutting and hand raking are returned as options for this section of watercourse, this reach needs to be placed in the context of the full 20 km that requires management, a distance over which manual techniques are unfeasible.

Consequently, the number of possible management techniques at this site is limited, with weed boats and amphibious vehicles being the highest ranked techniques effective for all three problem species in-combination. These were not the highest ranked technique for any of the three problem species and this case study highlights the importance of taking site-specific considerations into account.


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De-weeding with a weed bucket is also returned as a possible option, although with a relatively low ranking, given the sensitivity of artificial drainage channels to sediment mobilisation and the amount of sediment that this technique can generate.

Given the site-specific considerations detailed above, this method was selected as the most appropriate for this watercourse.

A stringent management plan, agreed with the Environment Agency and Natural England was followed to limit the potential adverse impacts of using this technique, including retention of wide vegetated margins so that the weed bucket did not come into contact with the banks, thereby limiting sediment mobilisation.

A number of long-term management strategies may also be effective for these species. These are:

- buffer strips and diffuse and point source pollution management to manage nutrient inputs
- encouraging broad-leaved floating species to create shading – though this would not be effective for yellow water-lily *Nuphar lutea*

Watercourse Name

Moretons Leam

Location

Cambridgeshire

WFD Watercourse number: GB105032050382
Start Grid Reference: TL27289846
End Grid Reference: TL31869924

Prepared by: Laura Thomas
Date: 11/08/2013

Is the watercourse a designated site or is it adjacent to a designated site? Yes - site is of national importance (eg SSSI, NNR)

You must contact Natural England/Natural Resources Wales prior to undertaking any vegetation management as a site management plan may already be in place and/or appropriate techniques/working methods will need to be agreed. Consent must be obtained under the Wildlife and Countryside Act 1981 (as amended). See section 4.5.1 of the Technical Guide.

Does the watercourse support populations of protected species (eg Water Vole, Otter, White-clawed Crayfish)? Yes

Contact Natural England/Natural Resources Wales/Environment Agency for further advice and follow appropriate species guidance. See section 4.5.2 of the Technical Guide.

Select Species

Data must be entered into all the white cells in this section before any recommendations can be made

Submerged Pondweeds Potamogeton spp. (e.g. Fennel Pondweed)

Select Watercourse Type

Artificial Drainage Channel

Length of watercourse to be managed (m): 4700
Channel width (m) (ie wetted width): 4
Water depth (m): 1.5

Machine access possible? Yes
Boat access possible? Yes

Notes for selected species:

Species identification of submerged pondweeds is important as this group contains some relatively scarce species (e.g. Grass Wrack Pondweed Potamogeton compressus, Sharp-leaved Pondweed, P. acutifolius)

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1	Shading with native, broad-leaved floating species	7.5.1		2	0.00	1	2.00	£
2	Weed boats	7.3.2		2	0.17	1	1.67	£
3	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.33	1	1.33	££
4=	Amphibious vehicles	7.3.2		2	0.50	1	1.00	£
4=	Hand cutting	7.3.1		1	0.00	1	1.00	£££
4=	Native fish species	7.6.4		1	0.00	1	1.00	£
7=	Buffer Strips	7.5.6		1	0.17	1	0.83	££
7=	Diffuse and point source pollution management	7.5.6		1	0.17	1	0.83	£££
7=	Hand pulling	7.3.1		1	0.17	1	0.83	£££ / £ (*)
10	De-weeding with a weed bucket	7.3.3		2	0.67	1	0.67	££
11=	Hand raking	7.3.1		1	0.50	1	0.50	£££
11=	De-weeding with a solid bucket	7.3.4		3	0.83	1	0.50	£££

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)

The maximum possible score is 3

(*) = lower cost if use volunteers

Figure 9.4 Screenshot of output from spreadsheet tool for Moretons Leam

9.4 River Lee, Luton

The River Lee flows through the town of Luton in Bedfordshire. It is a chalk stream and has low flows in summer, but potentially high winter flows.

A significant part of this stretch of the River Lee flows through parkland and residential areas, with numerous bridges, sluices, weirs, culverts and outfalls present. Access for machinery along the bank tops is restricted.

Problem species

Within the length of watercourse to be managed, two species types are problematic:

- tall emergent species, primarily branched bur-reed *Sparganium erectum*, but also some stands of reed sweet-grass *Glyceria maxima* and reed canary-grass *Phalaris arundinacea*
- broad-leaved emergent species, primarily fool's water-cress *Apium nodiflorum*, but also occasionally water-cress *Rorippa nasturtium-aquaticum*

The need for management

Flood risk management is the primary driver for watercourse management. There are many houses in the north Luton area that are at serious risk of rapid flooding during periods of heavy rainfall. The urbanised catchment and topography leads to a flashy response and during peak flows the channel capacity is insufficient to convey the water. Management is required to ensure maximum flow capacity within the channel.

The branched bur-reed *Sparganium erectum* and fool's water-cress *Apium nodiflorum* impede the flow of flood waters and cause the accumulation of debris. The fool's water-cress can also cause blockages if it becomes dislodged during high flows. As summer flooding can be an issue, the dense summer growth of these species can be problematic.

The aim of management is to keep flood flow capacity at optimal levels by keeping the channels relatively clear of vegetation all year round.

The River Lee has a thriving water vole *Arvicola amphibius* population. Management of the river therefore has to ensure there are no adverse impacts on this population.

The specific management **objectives** for River Lee are to:

- prevent and/or remove debris blockages affecting flow
- prevent growth of wood vegetation on lower banks and bed
- limit unstable bed/channel vegetation (that is, broad-leaved emergent species)
- restrict growth of stable emergent bed vegetation (that is, tall emergent species) to less than 30% of the channel width
- remove siltation affecting flood flows
- manage soft bankside vegetation to enable woody vegetation control

Using the spreadsheet tool

Table 9.5 summarises the data inputs to the spreadsheet tool.

Table 9.5 Data inputs to spreadsheet tool for River Lee

Parameter	Input
Is the watercourse a designated site or is it adjacent to a designated site?	No
Does the watercourse support populations of protected species (for example, water vole, otter, white-clawed crayfish)?	Yes– the River Lee has a thriving water vole *Arvicola amphibious* population
Problem species	Branched bur-reed *Sparganium erectum* Fool's water-cress *Apium nodiflorum*
Watercourse type	Inactive single thread channel
Length of watercourse to be managed (m)	3,000 m
Channel width (m) (that is, wetted width)	The section requiring management is approximately 3–4 m wide (a minimum of 3 m inputted)
Water depth (m)	0.5 m
Machine access possible?	No
Boat access possible?	No

Along the 3 km length of watercourse to be managed, the problem species varies. Branched bur-reed *Sparganium erectum* is the main problem, with small patches of fool's water-cress *Apium nodiflorum* interspersed between. As this site contains two problem species the spreadsheet tool was run twice, with the species changed on each run. The outputs are compared in Table 9.6. Given the restrictions for machine access, only eight possible techniques were returned for each species. The output for fool's water-cress is shown in Figure 9.5.

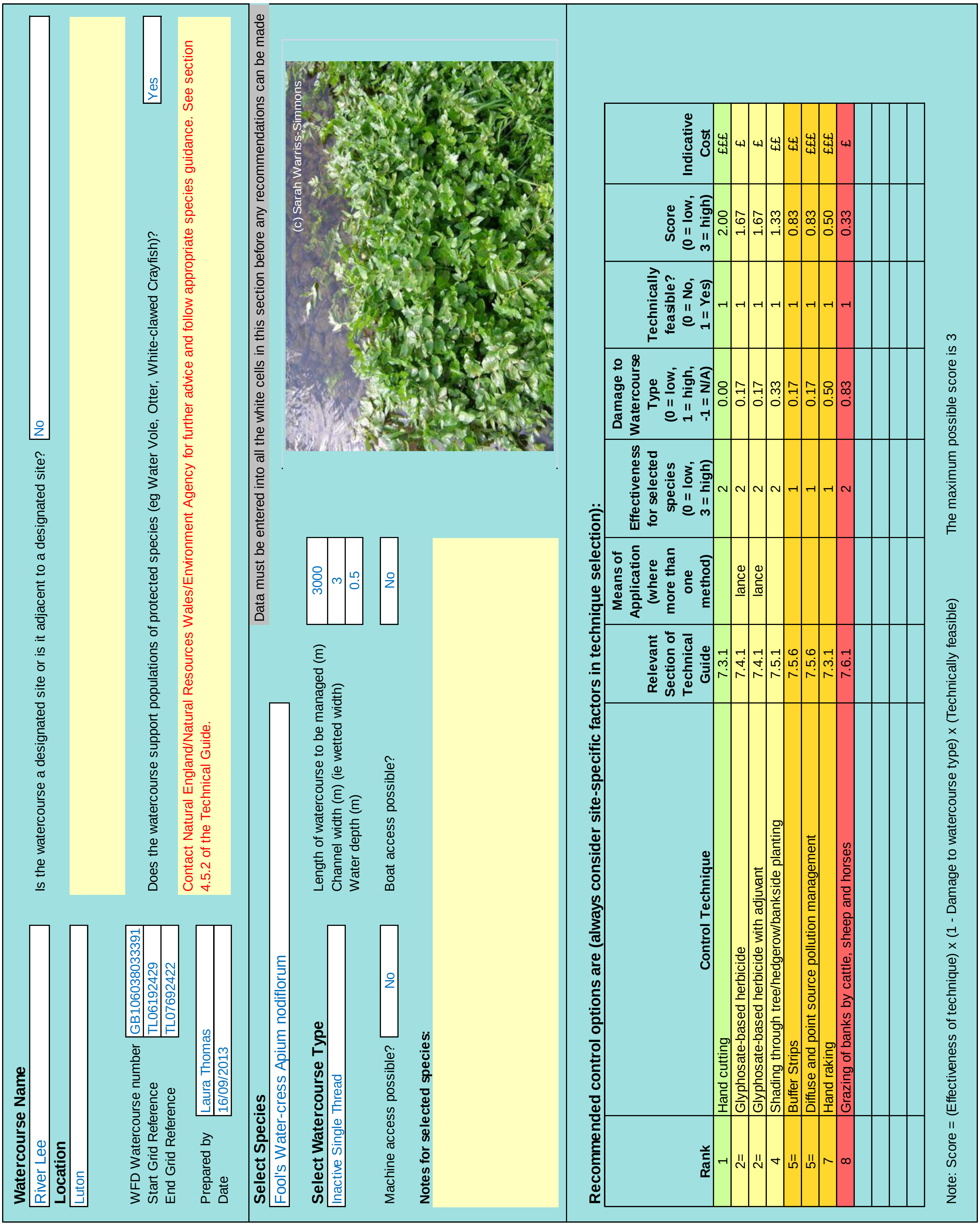
Table 9.6 Data outputs for two problem species in the River Lee

Technique	Branched bur-reed	Fool's water-cress
Glyphosate-based herbicide	1=	2=
Glyphosate-based herbicide with adjuvant	1=	2=
Hand cutting	3	1
Shading through tree/ hedgerow/ bankside planting	4	4
Buffer strips	5=	5=
Diffuse and point source pollution management	5=	5=
Hand pulling	5=	
Grazing of banks by cattle, sheep and horses	8	8
Hand raking		7

The ranked list of returned techniques for both problem species is very similar. In this case a common technique, or combination of techniques, can therefore be found which will be effective in managing both species. The top three ranked techniques for both species, although in differing orders are glyphosate-based herbicide, glyphosate-based herbicide with adjuvant and hand cutting.

Currently the management approach on the River Lee consists of hand cutting dense stands of broad-leaved vegetation, such as the fool's water-cress, with the branched bur-reed managed approximately every five years using an excavator fitted with a solid bucket. However, use of a glyphosate-based herbicide was trialled in 2013 due to the access restrictions, expense, waste disposal issues and potential environmental damage caused by an excavator fitted with a solid bucket. This approach is supported by the outputs of the decision-making tool.

A longer-term strategy could be is to increase shading of the watercourse through bankside planting. Tree and hedgerow planting is likely to be the most effective and could be carried out in some places to reduce long-term management costs. Nutrient and pollution management may help reduce vegetation growth in the longer term.



Watercourse Name
River Lee
Location
Luton

WFD Watercourse number: GB106038033391
Start Grid Reference: TL06192429
End Grid Reference: TL07692422

Prepared by: Laura Thomas
Date: 16/09/2013

Is the watercourse a designated site or is it adjacent to a designated site? No

Does the watercourse support populations of protected species (eg Water Vole, Otter, White-clawed Crayfish)? Yes

Contact Natural England/Natural Resources Wales/Environment Agency for further advice and follow appropriate species guidance. See section 4.5.2 of the Technical Guide.

Select Species
Fool's Water-cress Apium nodiflorum

Data must be entered into all the white cells in this section before any recommendations can be made

Select Watercourse Type
Inactive Single Thread

Length of watercourse to be managed (m): 3000
Channel width (m) (ie wetted width): 3
Water depth (m): 0.5

Machine access possible? No
Boat access possible? No

Notes for selected species:

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1	Hand cutting	7.3.1		2	0.00	1	2.00	£££
2=	Glyphosate-based herbicide	7.4.1	lance	2	0.17	1	1.67	£
2=	Glyphosate-based herbicide with adjuvant	7.4.1	lance	2	0.17	1	1.67	£
4	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.33	1	1.33	££
5=	Buffer Strips	7.5.6		1	0.17	1	0.83	££
5=	Diffuse and point source pollution management	7.5.6		1	0.17	1	0.83	£££
7	Hand raking	7.3.1		1	0.50	1	0.50	£££
8	Grazing of banks by cattle, sheep and horses	7.6.1		2	0.83	1	0.33	£

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)

The maximum possible score is 3

Figure 9.5 Screenshot of output from spreadsheet tool for River Lee

9.5 Boating Dike, South Yorkshire

Boating Dike is located within the town of Thorne, near Doncaster in South Yorkshire. The section of concern flows through the Capitol Park Business Park, before discharging under the M18 motorway and into the old course of the River Don via a series of culverts, one of which has a weedscreen and cleaner to remove accumulated debris.

When the Capitol Park industrial estate was developed in the late 1990s the watercourse was diverted. Further expansion of the industrial estate in 2006-2007 resulted in additional works to increase the capacity of this watercourse, along with installation of the weedscreen cleaner. During the second phase of engineering works a berm, below the usual water level, was included within the channel profile and there was extensive planting of marginal vegetation.

Problem species

The species of concern at Boating Dike is currently common duckweed *Lemna minor*. This completely covers the water surface, blocking structures causing localised flood risk issues and leading to impoverished submerged flora and fauna.

Historically, the problem species in this watercourse had been branched bur-reed *Sparganium erectum* and reed sweet-grass *Glyceria maxima* which reduced conveyance and channel capacity. Traditionally these tall emergent species were managed through flail mowing of bankside and marginal plants, and de-weeding with a weed bucket undertaken within the channel.

In 2012 the management method was changed due to difficulties with access for de-weeding machinery, the large volume of waste material generated, and the limited areas to deposit this waste. A glyphosate-based herbicide application was selected as the alternative technique, with spraying along the central part of the channel.

2010 – pre-herbicide application

2013 – post-herbicide application

The need for management

Being located in an urban and industrial setting, the primary driver of management is flood risk management, although the watercourse is also part of the land drainage network of the Black Drain Drainage Board. In June 2007 the area suffered from extensive flooding as a result of overtopping of the banks. Ensuring the channel is kept relatively clear of vegetation to maintain its capacity and ensure that flows of water are not impeded is therefore a priority.

© Black Drain Drainage Board

Management of the extensive infestations of common duckweed *Lemna minor* is also likely to lead to ecological benefits by allowing light into the channel, which should allow submerged flora and fauna to increase.

The management **objectives** for Boating Dike are to:

- ensure channel capacity is maintained and conveyance is not impeded by tall emergent vegetation
- prevent blockages from the accumulation of common duckweed *Lemna minor* and other plant debris.

Using the spreadsheet tool

Table 9.7 summarises the data inputs to the spreadsheet tool.

Table 9.7 Data inputs to spreadsheet tool for Boating Dike

Parameter	Input
Is the watercourse a designated site or is it adjacent to a designated site?	Yes – the watercourse discharges into the Thorne Watersides, Oxbows and Ings local wildlife site
Does the watercourse support populations of protected species (for example, water vole, otter, white-clawed crayfish)?	Yes – the watercourse is known to support a population of water vole *Arvicola amphibius*
Problem species	Common duckweed *Lemna minor*
Watercourse type	Ditch/ small drain
Length of watercourse to be managed (m)	735 m
Channel width (m) (that is, wetted width)	5–6 m (minimum of 5 m inputted)
Water depth (m)	0.5 m
Machine access possible?	Yes
Boat access possible?	No

The ranked list of outputs returned shading with native, broad-leaved floating species as the most effective solution (Figure 9.6). However, planting of such species may create further issues with conveyance and channel capacity and so is not advised at this site. Alternatively, shading with tree/ hedgerow/ bankside would be an effective control technique, but given the limited access along the bank top at this site and the presence of a public footpath, there is limited space available for planting.

The second highest ranked option is channel narrowing to increase velocity through creation of a two-stage channel. This option has been considered previously to reduce the extent of tall emergent vegetation through installing toe piling within the channel, although has not yet been implemented. This could therefore be selected as a long-term strategy, which should help to reduce the long-term management requirements of this watercourse. However, the flood risk implications of this option would need to be carefully assessed as the current watercourse capacity has been designed in relation to the business park development. Other longer-term options, including buffer strips and reduced diffuse and point source pollution, are also relatively highly ranked techniques.

These longer-term techniques would not resolve the issue in the short term. The highest ranked short-term option was the use of the novel suction harvesting technique. The expense and resources required to use this technique may make this an unfeasible option.

Watercourse Name
Boating Dike
Location
Thorne, South Yorkshire

Is the watercourse a designated site or is it adjacent to a designated site? Yes - site is of local importance (eg LNR, LWS, etc)

Liaise with local planning authority/site owner or manager with regards to appropriate techniques/working methods and a site management plan may already be in place.

WFD Watercourse number: n/a
Start Grid Reference: SE67771338
End Grid Reference: SE67501340

Does the watercourse support populations of protected species (eg Water Vole, Otter, White-clawed Crayfish)? Yes

Contact Natural England/Natural Resources Wales/Environment Agency for further advice and follow appropriate species guidance. See section 4.5.2 of the Technical Guide.

Prepared by: Laura Thomas
Date: 18/10/2013

Select Species
Duckweeds Lemna spp

Data must be entered into all the white cells in this section before any recommendations can be made

Select Watercourse Type
Ditch / Small Drain

Length of watercourse to be managed (m): 735
Channel width (m) (ie wetted width): 5
Water depth (m): 0.5

Machine access possible? Yes
Boat access possible? No

Notes for selected species:
Care should be taken in identification as Rootless Duckweed Wolffia arrhiza is a rare species in this group.

Recommended control options are (always consider site-specific factors in technique selection):

Rank	Control Technique	Relevant Section of Technical Guide	Means of Application (where more than one method)	Effectiveness for selected species (0 = low, 3 = high)	Damage to Watercourse Type (0 = low, 1 = high, -1 = N/A)	Technically feasible? (0 = No, 1 = Yes)	Score (0 = low, 3 = high)	Indicative Cost
1	Shading with native, broad-leaved floating species	7.5.1		2	0.00	1	2.00	£
2=	Channel narrowing to increase velocity (two-stage channel)	7.5.5		2	0.33	1	1.33	£££
2=	Shading through tree/hedgerow/bankside planting	7.5.1		2	0.33	1	1.33	££
2=	Suction harvesting	7.7.4		2	0.33	1	1.33	£££
5	Native fish species	7.6.4		1	0.00	1	1.00	£
6=	Buffer Strips	7.5.6		1	0.17	1	0.83	££
6=	Diffuse and point source pollution management	7.5.6		1	0.17	1	0.83	£££
6=	Glyphosate-based herbicide	7.4.1	lance	1	0.17	1	0.83	£
6=	Glyphosate-based herbicide with adjuvant	7.4.1	lance	1	0.17	1	0.83	£
10	De-weeding with a weed bucket	7.3.3		1	0.67	1	0.33	££
11	De-weeding with a solid bucket	7.3.4		1	0.83	1	0.17	£££

Note: Score = (Effectiveness of technique) x (1 - Damage to watercourse type) x (Technically feasible)   The maximum possible score is 3

Figure 9.6 Screenshot of output from spreadsheet tool for Boating Dike

10. Monitoring

It is essential to monitor the impacts arising from the management of aquatic and riparian vegetation, by all techniques, to ensure that:

- the management has been successful and the desired outcome has been achieved
- any repeat or follow-up treatments can be carried out, when and where necessary
- any unanticipated environmental or geomorphological impacts are identified so that the management regime can be adapted

Monitoring should be an integral part of planning and implementing all vegetation management operations. All too frequently it is not conducted in a coherent and strategic manner, with at best ad hoc observations made.

It is recommended that robust monitoring is integrated into the planning and implementation of vegetation management. As management of vegetation in watercourses can be a regular and routine operation, it is important that monitoring:

- is not onerous
- is proportionate to the activity
- can be conducted by those on the ground
- does not require any specialist equipment or skills

This chapter outlines the importance of applying principles of adaptive management to aquatic and riparian vegetation management. It details monitoring methodologies that could be employed to monitor impacts and proposes a generic monitoring framework that could be used where required in the absence of existing monitoring programmes.

10.1 Adaptive management

Monitoring allows for implementation of an adaptive management approach (Figure 10.1). Adaptive management enables structured, iterative decision-making, allowing uncertainty to be reduced and unanticipated impacts to be mitigated against. It also allows the outcomes of future operations to be improved. Adaptive management allows lessons to be learnt, and feedback and alterations to be made to provide improvements over the long-term. Adaptive management can be either passive, where a predictive model based on present knowledge is used to inform management decisions which then is updated and management adapted as knowledge is gained, or active, where management is adapted to test new hypotheses and a more experimental approach is adopted.

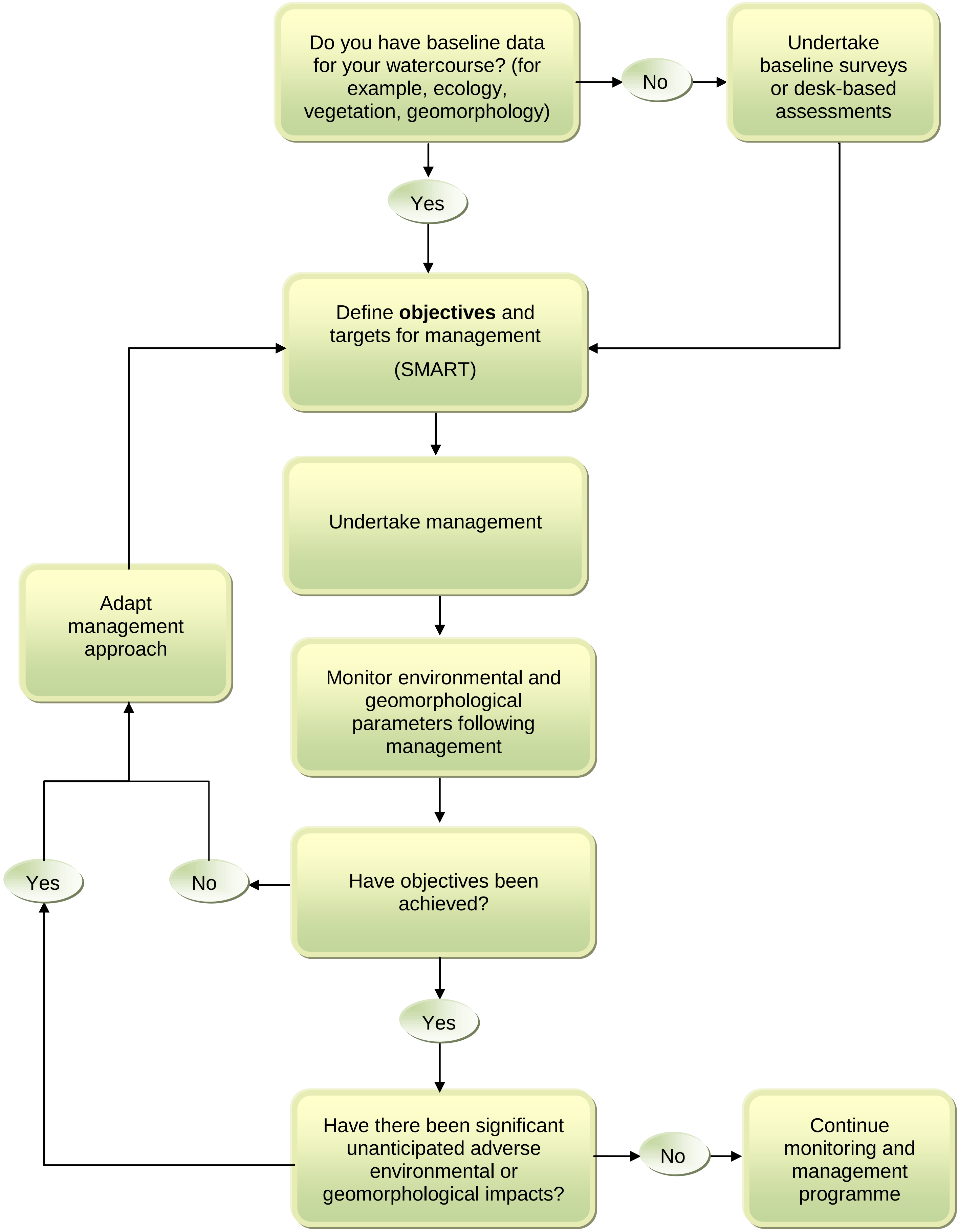


Figure 10.1 Monitoring and adaptive management approach

Passive adaptive management is more likely to be used in aquatic and vegetation management, where management is implemented, monitored and then alterations made based on the knowledge collected as and when required.

Active adaptive management may be used where novel techniques are employed, or in situations where a technique is used at a site where it has not previously been tried.

Although monitoring and adaptive management may, in some cases, result in the technique used being changed entirely, in other cases, it may just alter the way the chosen technique is implemented. An example might be by increasing the width of marginal vegetation retained to prevent loss of species diversity.

10.2 Existing watercourse monitoring programmes and methods

Numerous programmes and methods are available to monitor watercourses, either for a specific feature, such as macroinvertebrates or fish, or a broad range of parameters, for example, data collected as part of a river habitat survey. Existing monitoring programmes can be useful, allowing assessment and monitoring of the impacts of vegetation management to be undertaken with little additional cost.

Table 10.1 summarises a number of existing monitoring programmes and methods used in relation to watercourses. These are likely to be those of most use when monitoring the impacts of aquatic and riparian plant management. Where present, the results of these monitoring programmes could be assessed to determine the impact of aquatic and riparian vegetation management works. In many cases a combination of monitoring methodologies may be the best approach.

Table 10.1 Existing watercourse monitoring methodologies

Monitoring protocol	Description
Fixed point photography	Photographs taken at a preset permanent location(s) at specified time periods. This method allows broad-scale changes in vegetation, habitat and geomorphology to be assessed. **Advantages**: A simple method not requiring any specialist knowledge or skills.
River habitat survey (RHS) (Environment Agency et al. 2003)	A standard, replicable methodology that maps habitats from a walkover survey along a 500 m stretch of river. Vegetation, key morphological features and other aspects of interest within the river corridor are also recorded. Spot checks at 50 m intervals and tick lists of features (that is, bank and channel characteristics, modifications, land use and vegetation structure) are included within a provided proforma to standardise data collection and allow comparison of reaches. RHS is the tool selected for monitoring hydromorphology for the Water Framework Directive. Geo-river habitat surveys are an enhanced RHS with more focus on the geomorphology and sediment transport, including additional cross-section information. The methodology has also been adapted for urban situations or highly modified watercourses as part of the urban river survey (URS). **Advantages**: Collects data on a broad range of parameters

Monitoring protocol	Description
	through undertaking of a relatively rapid walkover survey. Can be adapted to focus on specific issues (for example, geomorphology and urban environments) and data can be stored in a central database.
River corridor survey (RCS)	Produces standardised maps of vegetation structure along a specified stretch of watercourse. It looks at both physical habitat and botanical communities. **Advantages**: Collects data on both physical and botanical parameters and is a widely used survey method. Mapping allows for comparison between surveys undertaken at the same location at pre- and post-management.
Aerial photography	Useful to provide an overview of the watercourse concerned, particularly when monitoring the extent of problem species, for example non-native invasive species. It is relatively limited in relation to vegetation management. **Advantages**: A large area can be monitored in a relatively short period of time, although analysis time is also required. Relatively cost-effective.
Fluvial audit	Provides baseline information about the current condition of a watercourse in terms of its form and physical processes, including sediment transport, erosion and deposition. Repeat surveys pre- and post-management allow for changes in physical conditions to be identified. It does not specifically assess vegetation and some specialist knowledge is required. **Advantages**: Allows the physical changes in a watercourse to be identified relatively rapidly.
Geomorphological mapping	Similar to a fluvial audit, but more heavily focused on watercourse bed, bank and floodplain features, rather than processes, which are mapped. Repeat surveys pre- and post-management allow for changes in watercourse morphology to be identified. It does not specifically assess vegetation and some specialist knowledge is required. **Advantages**: Allows the changes to the physical condition of a watercourse to be identified relatively rapidly.
Aquatic macrophyte surveys	These are surveys that focus on the vegetation present within a watercourse. These can follow bespoke or set methods. One option is the LEAFPACS survey method which involves measuring the abundance of macrophytes in a 100 m survey length (UKTAG 2013b). These surveys should always be carried out between June and September, in average to low flow conditions. This method is also used as part of WFD monitoring. Geomorphological parameters are not assessed and some specialist knowledge is required. **Advantages:** Allows change in vegetation composition and cover between growing seasons pre- and post-management to be assessed.

Monitoring protocol	Description
Quadrat/ National Vegetation Classification (NVC) survey	Detailed botanical analysis typically using 1 × 1 m or 2 × 2 m quadrats. Data on percentage cover are also recorded and, when using NVC, typical communities can be assigned. This technique may be less applicable in aquatic habitats. It requires specialist expertise in species identification. **Advantages**: Allows change in vegetation composition and cover between growing seasons pre- and post-management to be assessed.
JNCC common standards monitoring	The JNCC has developed a series of common standards monitoring guidance documents for a range of habitat types within the UK, including rivers, ditches and canals. Generally for watercourses, this methodology requires surveying a 500 m reach within approximate 5 km length of watercourse. Different parameters are then surveyed depending on the watercourse type. Data on vegetation, habitat structure, channel form, land use and water quality are collected. The guidance documents are available from the JNCC website (http://jncc.defra.gov.uk/page-2199). **Advantages**: Collects data on a broad range of parameters through undertaking of a relatively rapid walkover survey.
Macroinvertebrate survey	There are many techniques which can be used to sample aquatic macroinvertebrates. The most frequently used is the RIVPACS method which involves a three-minute kick sample, where the surveyor actively disturbs the bed of the watercourse with their foot dislodging invertebrates and collecting them in a net. This is supplemented by a one-minute hand search of stones and other moveable features. Abundance for each family or (with more specialist expertise) species can be compiled, which can then be statistically analysed to evaluate the invertebrate communities using specialist indices. These surveys are typically undertaken over two seasons – spring (March to May) and autumn (September to November). **Advantages**: When undertaken pre- and post-management they can be used to compare the communities present and assess impact.
Fish surveys (angler catch data, electric fishing, netting, trapping, fish-counters, hydro-acoustic surveys)	Numerous methods are available which can be used to survey fish populations within a watercourse, which vary in applicability, complexity and expense. Where fish monitoring is already in place it can be used to assess the impacts of management by comparing baseline data with post-management information. **Advantages**: When undertaken pre- and post-management they can be used to compare the fish populations present and assess impact.
Water level monitoring	Monitoring of water levels provides a good understanding of hydrological conditions within a watercourse and can be used to provide useful information to assess the hydraulic and hydrological impact of vegetation management operations. Existing networks of gauging stations, dataloggers and gauge boards could be used. This would need to be used in

Monitoring protocol	Description
	combination with other monitoring to assess vegetation and geomorphological changes. **Advantages**: Can be used to support other monitoring results to gain a broader understanding of hydrological conditions.
Water flow monitoring	Monitoring of water flows and velocities provides a good understanding of hydrological conditions within a watercourse and can be used to provide useful information to assess the hydraulic and hydrological impact of vegetation management operations. Existing networks could be used or direct measurements taken. This would need to be used in combination with other monitoring to assess vegetation and geomorphological changes. **Advantages**: Can be used to support other monitoring results to gain a broader understanding of hydrological conditions.

10.3 Developing a monitoring protocol

Where existing monitoring programmes are not in place or they are not suitable to assess the impact of aquatic and riparian vegetation management, it will be necessary to develop a specific monitoring programme. This section sets out the key principles that need to be considered when developing an adaptive monitoring programme to assess the impacts management and outlines generic protocols that could be used.

To indicate the level of success of management undertaken, monitoring needs to be an integral part of the process, from inception, through to completion of the operation and subsequently throughout ongoing management cycles.

Given the aims and potential impacts of aquatic and riparian vegetation management, it is important that any monitoring programme established takes account of both environmental and geomorphological parameters, alongside direct impacts on vegetation communities.

It should be recognised that watercourses can be complex ecological and geomorphological systems in which complex responses can occur and within which there is a high degree of variability. This needs to be considered when developing any monitoring protocol.

10.3.1 Baseline data

To determine whether a management operation has had an environmental impact, negative or positive, it is important to have an understanding of the baseline ecology and geomorphology. This provides a benchmark against which the changes post-management can be compared, with any significant or unanticipated changes potentially triggering an alteration in the management regime developed (that is, adaptive management).

In many cases sufficient data and knowledge will be available to enable an adequate baseline to be compiled. As a minimum the following should be understood:

- current vegetation composition (ideally to species level) and cover (see Chapter 5)
- presence of any protected or notable species or other environmental constraints (see section 4.4)
- watercourse type (see Chapter 6)

Additional desk-based assessments and surveys should be conducted to ensure all necessary baseline data are available.

Possible sources of information for a desk-based assessment include:

- Multi Agency Geographic Information for the Countryside (MAGIC) (www.magic.gov.uk)
- National Biodiversity Network (NBN) Gateway (https://data.nbn.org.uk)
- Local Environmental Records Centres (www.alerc.org.uk)

It is essential to collect and collate the baseline data and monitoring information from existing programmes or otherwise in a form that can answer the management objective(s).

10.3.2 Objectives and targets

To determine whether management has been successful, it is vital that clear objectives and targets are set before any management begins. In relation to aquatic and riparian plant management there will be an overall objective for the management operation (see section 4.1), alongside which specific monitoring objectives can be set. It is important that objectives are **S**pecific, **M**easurable, **A**chievable, **R**ealistic and **T**ime-scaled (**SMART**).

- **Specific** – the objective(s) should be clear, detailed, focused and well-defined and emphasise the action and required outcome.
- **Measureable** – it should be possible to assess achievement of the objective(s), usually quantitatively, and this will also allow for comparison.
- **Achievable –** it should be possible to meet the objective(s) and they should not be unfeasible or unobtainable.
- **Realistic** – it should be possible, given the resources available to meet the objective(s), and while it may not be easy to meet, it should not be impossible.
- **Time-scaled** – deadlines should be set for achievement of the objective(s).

10.3.3 Determining the level of monitoring required

The level of monitoring required will depend on:

- the technique selected
- the target species
- the watercourse type
- other environmental considerations at the site

For example, techniques that have been used for a considerable period of time, across wide geographical areas and on a variety of watercourse types, such as de-weeding with a weed bucket in artificial drainage channels, are likely to have more widely understood impacts. The level of monitoring required may be proportionally less than that required for a novel technique, such as hot foam or Hydro Venturi, or a technique that requires extensive, invasive works to be undertaken within the channel, for example water level manipulation or water flow manipulation through creation of a two-stage channel.

The level of monitoring conducted should be related to the predictability and controllability of the technique. Those techniques where the impacts are highly predictable, such as using an excavator mounted flail or cutter, may require proportionally less monitoring effort than techniques where the impact is more uncertain, for example grazing, the use of fish or shading techniques.

The scale of the management operation will also influence the amount of monitoring required. Small-scale management operations on short lengths of watercourse are likely to require less monitoring effort than widespread, comprehensive management programmes covering long lengths of watercourse.

10.3.4 Spatial extent and timescales

The spatial extent and timescale of monitoring should be determined on a site-specific basis, influenced by the technique selection.

For watercourses where management is conducted over long lengths using traditional techniques, such as de-weeding with a weed bucket, it would be unrealistic to monitor the full length of watercourse where the operation has been conducted. Strategic monitoring points need to be established to allow for realistic monitoring effort to be undertaken; however, comprehensive coverage of the system will be needed so that the inherent variability within watercourses can be taken account of.

Deciding when to conduct monitoring and the frequency of sampling will depend on the site and the technique implemented. Some techniques, including the longer-term management strategies such as shading with vegetation or nutrient management, are likely to require very infrequent monitoring, but over several years (or decades). Techniques with a much shorter-term impact, such as de-weeding with a weed bucket, may require a number of monitoring visits within the same growing season.

The spatial extent, frequency and detail of monitoring will, to some extent, be a matter of expert judgement and depend on the management objective(s).

10.4 Proposed monitoring protocol

This section outlines a generic monitoring protocol recommended for adoption where no existing monitoring programme is in place. This protocol should be implemented based on the principles discussed above. Depending on the site and management undertaken they can be implemented independently of, or in combination with, each other. This monitoring protocol can be used where the existing monitoring programme does not adequately assess the impacts of the vegetation management.

The proposed monitoring protocol is designed to be simple, straightforward and implementable by technical and operational staff within the operating authorities responsible for watercourse management. It is based on fixed point photography and/ or collection of basic information on the habitat, including vegetation composition and cover, and geomorphological features, based on RCS methodologies.

Table 10.2 Generic monitoring protocol

Monitoring aspect	Description	Method
Fixed point photography	Photographs taken at a preset permanent location(s) before, during, immediately after, and a considerable period after, the management work.	1. Establish fixed point locations. These should be at easily accessible locations, such as from bridges. The number of sites should be proportionate. 2. Take photographs prior to management. 3. Take photographs immediately following management. Assess if the management objective has been achieved. 4. Take photographs a set period(s) following management. Assess if the management objective has been achieved and determine if any adverse impacts have arisen.
River corridor survey (RCS) Recording of vegetation composition and cover	Map 50 m length of watercourse and record vegetation, habitats and geomorphological features. The species present and their coverage should also be noted.	1. Identify survey reaches. These should be at easily accessible locations, such as from bridges. The number of sites should be proportionate. 2. Map habitats, vegetation and geomorphological features prior

Monitoring aspect	Description	Method
Habitat and geomorphological feature mapping		to management and record species present and their coverage. 3. Map habitats, vegetation and geomorphological immediately following management and record species present and their coverage. Assess if the management objective has been achieved. 4. Map habitats, vegetation and geomorphological a set period(s) following management and record species present and their coverage. Assess if the management objective has been achieved and determine if any adverse impacts have arisen.

Figure 10.2 summarises the monitoring process that should be followed. Determining whether adverse impacts have arisen will be informed by the baseline data collected and also professional judgement and knowledge of the watercourse being managed.

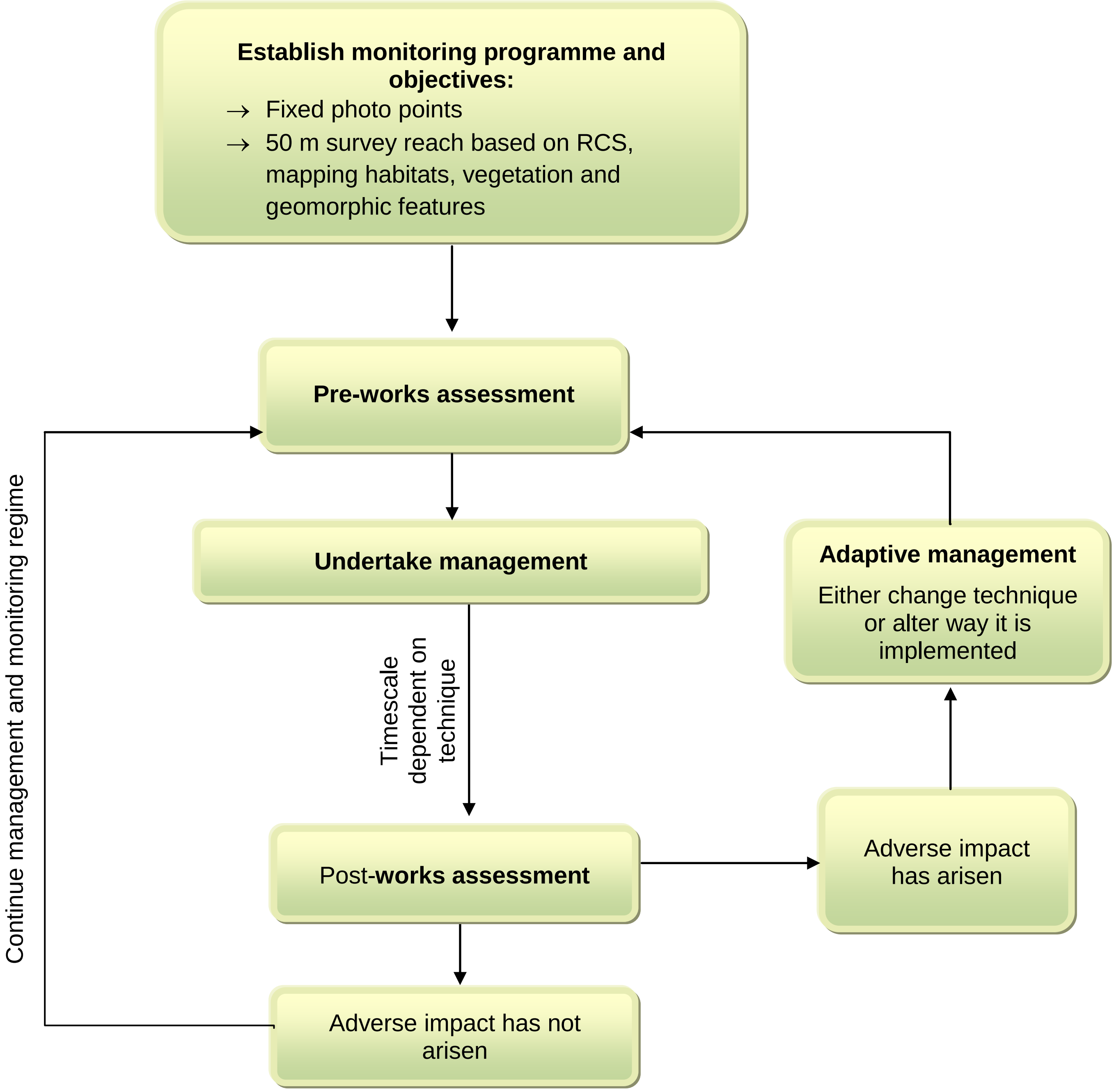


Figure 10.2 Monitoring process

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List of abbreviations

AONB	Area of Outstanding Natural Beauty
ATV	all-terrain vehicle
AWB	artificial water body
BAP	Biodiversity Action Plan
BSBI	Botanical Society of Britain and Ireland
CES	Conveyance Estimation System
COSHH	Control of Substances Hazardous to Health
CRD	Chemical Regulations Directorate
EIA	Environmental Impact Assessment
FCRM	Flood and Coastal Risk Management
FEH	Flood Estimation Handbook
GEP	good ecological potential
GES	good ecological status
HMWB	heavily modified water body
IDB	Internal Drainage Board
JNCC	Joint Nature Conservation Committee
LLFA	Lead Local Flood Authority
NERC	Natural Environment and Rural Communities Act 2006
NNSS	Non-Native Species Secretariat
NPTC	National Proficiency Test Certificate
NVC	National Vegetation Classification
OS	Ordnance Survey
PPE	personal protective equipment
RBMP	river basin management plan
RCS	river corridor survey
RHS	river habitat survey
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UKTAG	UK Technical Advisory Group
WCA	Wildlife and Countryside Act
WFD	Water Framework Directive

Glossary

Active single thread	Sand and fine gravel dominated watercourse with a low/ meandering gradient channel. Often dynamic channels, better connected floodplains. Bars, pools and riffles common.
Adjuvant	A herbicide additive used to increase absorption of the herbicide through the leaves of plants, or to help it remain on leaves for a longer period of time to increase effectiveness.
Algae	A very large and diverse group of simple, typically autotrophic organisms (able to get energy from light or chemical sources), ranging from unicellular to multicellular forms.
Aquatic vegetation	Plants that have adapted to living in salt or freshwater.
Base-poor	Acidic water environments.
Base-rich	Neutral or alkaline water environments.
Berm	A flat, small in-channel deposit, often lateral. In lowland watercourses they are often fine sediment dominated. Can also be artificially created.
Biodiversity	The variety of species within an ecosystem.
Biosecurity	A set of measures designed to reduce the risk of spread of problematic species or disease.
Boulder step	Boulder bed material, steep gradient and energetic/ turbulent flows.
Bryophyte	A plant that lacks vascular (xylem and phloem) tissue.
Cascade	A section of river with energetic flow. They are turbulent and could include a small vertical drop.
Chute	A channel cut through a bar deposit, created at times of higher flow in varying channel sizes. Have turbulent flow, often over boulder or bedrock.
Clasts	Fragments and smaller grains of rock broken off other rocks by physical weathering processes.
Deoxygenation	The removal of dissolved oxygen from the water.
Diatoms	A major group of algae, and are among the most common types of phytoplankton.
Diffuse pollution	Pollution which originates from various activities, and which cannot be traced to a single source and originates from a spatially extensive land use (for example, agriculture, settlements, transport, industry). Examples of diffuse source pollution are atmospheric deposition, run-off from agriculture,

	erosion, drainage and groundwater flow.
Ecology	The scientific study of the interaction between organisms and their environment.
Ecosystem	A community of living organisms (for example, plants and animals) in unison with the non-living components of their environment (for example, water, air, soil).
Emergent species	Plant species that grows in water with part of the plant growing above the water surface.
Epiphytic	A plant species that grows on another plant.
Erosion	The process by which soil or rock are removed by water or wind, which can cause instability of river banks and other structures.
Eutrophication	The enrichment of waters by inorganic nutrients that results in increased production of algae and/ or other aquatic plants, which can affect the quality of the water and disturb the balance of organisms present within it.
Floodplain	An area of land adjacent to a river or stream that will become inundated in a flood event.
Gabion basket	A wire mesh cage, usually filled with stone/ concrete for structural purposes or erosion control; they can also be filled with barley straw for management of algae.
Glide	Deeper, slow flowing sections of river with little water surface disruption.
Hydromorphology	Describes the hydrological and geomorphological processes and attributes of surface water bodies. For example, for rivers, hydromorphology describes the form and function of the channel as well as its connectivity (upstream and downstream, and with groundwater) and flow regime, which defines its ability to allow migration of aquatic organisms and maintain natural continuity of sediment transport through the fluvial system.
Internal Drainage Board	An operating authority that has permissive powers to undertake drainage works and water level management within specified drainage districts.
Island	Created through bifurcating flow around a stabilised section of bank, well vegetated, mixed sediment composition.
Keeled	When referring to leaves, the distinct sharp, angled edge along the midrib of the leaves.
Lateral bar	Deposition on one bank of the channel. Mixed sediment composition.
Lead Local Flood	County councils and unitary bodies that are required

Authority	to, amongst other responsibilities, prepare and maintain a flood risk management strategy, under the Flood and Water Management Act.
Ligule	The outgrowth at the junction of leaf and leafstalk of many grasses and sedges. Commonly, a thin translucent membrane or fringe of hairs.
Macroinvertebrate	An invertebrate (animal species that lacks a vertebral column) large enough to be seen without a microscope.
Macrophyte	Larger plants, typically including flowering plants, mosses and larger algae but not including single-celled phytoplankton or diatoms.
Main River	A statutory watercourse marked as such on a Main River map, usually large rivers and streams. One of the two statutory watercourses in England and Wales, the other being Ordinary Watercourses.
Mesotrophic	Water that has an intermediate productivity with some plant species present, but not extensively discoloured by algal growth.
Mid-channel bar	Deposition in the centre of the channel which becomes stabilised through infilling and vegetation colonisation. Have a mixed sediment composition.
Motile	Organisms with the ability to move spontaneously and actively, consuming energy in the process.
Mudstone	Sedimentary rock composed of fine grains of clay or mud.
Non-native invasive species	Any animal or plant that has been introduced (by intent or accident) that has the ability to spread causing damage to the environment or humans (economy, health and so on).
Oligotrophic	An organism that can survive in a nutrient-poor environment.
Oolite	A sedimentary rock formed from ooids (spherical grains of concentric layers made, most commonly, from calcium carbonate).
Operating authority	A body empowered under the Land Drainage Act 1991 or Water Resources Act 1991 to carry out drainage or flood protection work in England and Wales.
Ordinary Watercourse	A statutory watercourse which does not form part of a Main River, including rivers, streams, ditches and other passage through which water flows.
Passive single thread	Low gradient sections of river, often with a resistant bed and/ meandering banks (for example, clays). Less meandering dynamic but sinuous planform, often incised and glides dominate.

Perennial	A plant that lives for more than two years.
Petiole	The stalk of a leaf.
Photosynthesis	A process used by plants and other organisms to convert carbon dioxide and water into sugar and oxygen using light energy (from the Sun).
Phytobenthos	Bottom-dwelling multi-cellular and unicellular aquatic plants such as some species of diatom.
Phytoplankton	Unicellular algae and cyanobacteria, both solitary and colonial that live, at least for part of their lifecycle, in the water column.
Plane bed	Consistent bed and flow type, often with gravels and some cobbles, shallower than pools.
Poaching	Damage, compaction and churning up of soils by the trampling of livestock.
Point bar	Deposition on inside of bend associated with bank erosion on opposite bank, composed cobbles, gravels and fines.
Pool	Deeper sections of river, slower flows, shallow gradient, finer bed material than riffles and no water surface disruption.
Protected species	Plants and animals that are awarded protection from killing and disturbance under various UK and EU legislation.
Rapid	A section of river with steep gradient, coarse bed material (cobbles, possibly small boulders) and energetic/ turbulent flows.
Receptor	In relation to flood risk management, a receptor is an entity that may be impacted upon, such as a person, property or habitat.
Rhizome	The modified stem of a plant found underground, from which roots and shoots grow from nodes.
Riffle	A shallower section of river, with energetic flows, moderate gradient and coarser bed materials/ gravels. Symmetrical ripples are created, not waves. Flows are less turbulent.
Riparian trees	Trees found along watercourse in the riparian zone which form the link between the environments of water and land.
Riparian vegetation	The characteristic wetland vegetation along watercourses that forms the link between the environments of water and land.
Riparian zone	The area at the edge of watercourses.
Run	Similar to a riffle, but with fewer ripples and less turbulent.

Siltation	The pollution of water by small particles of soil or other particulate leading to increased concentration of suspended sediment and/or accumulation of sediment on the bed of the water body.
Site of Special Scientific Interest (SSSI)	A protected site in the UK designated for features of biological or geological interest.
Special Area of Conservation (SAC)	An area awarded special protection under the EU Habitats Directive.
Special Protection Area (SPA)	An area awarded protection under the EU Directive on the Conservation of Wild Birds.
Submerged species	Plants that live under the water surface.
Substrate	The material (for example, sand, rock, gravel, silt) found at the bottom of a water body.
Toxicity	The degree to which a substance can damage an organism.
Translocated	Absorbed and distributed throughout the plant to the roots and shoots.
Tuber	Modified plant structure, enlarged to store nutrients.
Turbidity	The degree of cloudiness of water.
Turion	A specialised bud produced by some aquatic plants in winter.
Typology	A classification based on general type or characteristics.
Wandering	A watercourse with characteristics of braided and active meandering watercourses, however, with smaller bed material size, shallower slope and wider valley floor, often sequences of bars, pools, riffles, rapids, runs.
Water Framework Directive	A European Union directive which commits Member States to achieve good qualitative and quantitative status of all water bodies.
Watercourse	A flowing water body.
Wet fences	Water-filled boundaries that limit the movement of livestock.

Appendix A Legislative review

This appendix provides a review of the current European and UK legislation relating to the management of aquatic and riparian plants. It identifies the legislation currently driving the need for aquatic and riparian plant management. It also describes the duties imposed and the regulations that must be taken into account when carrying the different plant control techniques, including duties relating to the safeguarding of the environment.

A.1 Legislation driving aquatic and riparian plant management

One of the main drivers of aquatic and riparian plant management is flood risk management. Landowners are legally responsible for maintaining the bed and banks of watercourses on their land so as not to cause flooding to other people's land. The Environment Agency, Internal Drainage Boards (IDBs), Lead Local Flood Authorities (LLFAs) and local authorities have permissive powers to maintain watercourses (which includes the management of aquatic and riparian plants) to manage flood risk, but are not under any legal obligation to do so.

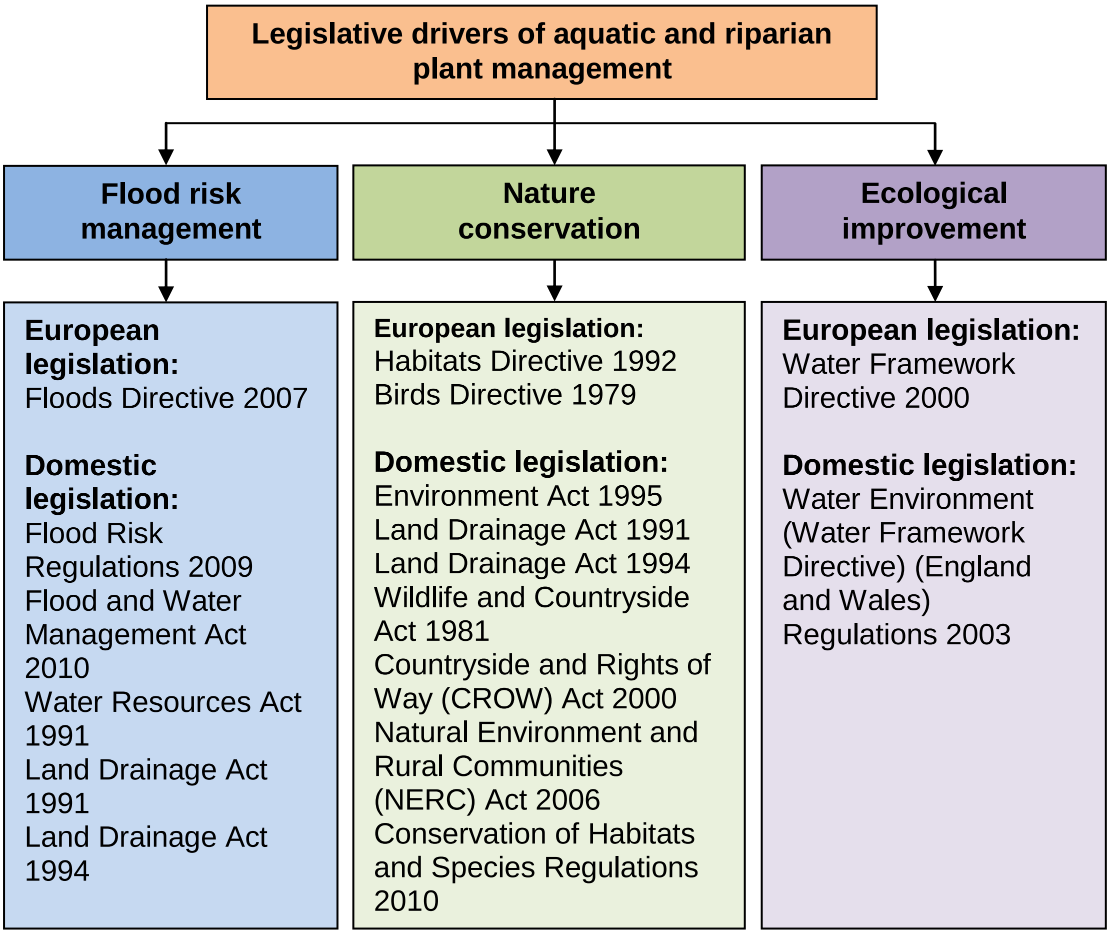

Figure A.1 Legislative drivers of aquatic and riparian plant management

These organisations and others – including the Canal & River Trust, Natural England, Wildlife Trusts, Angling Trust and private individuals – may also conduct aquatic plant management for reasons including navigation, irrigation, fisheries, amenity, nature conservation, ecological improvement and the control of non-native invasive species.

The following sections describe the legislation pertaining to these management drivers as shown in Figure A.1.

A.1.1 Flood risk management

The **Floods Directive** (2007/60/EC) establishes a framework for assessing and managing flood risk aimed at reducing the adverse consequences for human health, the environment, cultural heritage and economic activity. It was transposed into English and Welsh law by the **Flood Risk Regulations 2009** which came into force on 10 December 2009. The regulations require the preparation of flood risk assessments, maps and plans. The Environment Agency is responsible for preparing assessments, maps and plans for Main Rivers, sea and reservoir flood risk, whereas LLFAs are responsible for all other sources of flooding including where Main River, sea or reservoir flooding affects this.

In 2010, the **Flood and Water Management Act** gave the Environment Agency a strategic overview of all flood risk management activities. Welsh Ministers are responsible for this in Wales. The Act aims to improve both flood risk management and the management of water resources. The Act also creates clearer roles and responsibilities and instils a more risk-based approach to managing flooding. The Environment Agency and the Department for Environment, Food and Rural Affairs (Defra) have published a National Flood and Coastal Erosion Risk Management Strategy for England to ensure that government, the Environment Agency, IDBs, LLFAs, local authorities, water companies and other organisations that have a role in flood and coastal erosion risk management (FCERM) understand each other's roles and coordinate how they manage these risks. Similarly, the Welsh Government has produced a National Strategy for Flood and Coastal Erosion Risk Management in Wales.

The **Flood and Water Management Act** also includes a new role for LLFAs in managing local flood risk, including a requirement to develop, maintain, apply and monitor a Local Flood Risk Management Strategy (LFRMS), in which aquatic and riparian vegetation management will often play a key role.

Of relevance to the management of aquatic and riparian plants, the Environment Agency (under section 165 of the **Water Resources Act 1991** (as amended)) and IDBs/ local authorities (under the **Land Drainage Act 1991** section 14 (as amended)) have powers 'to maintain existing flood risk management works including cleansing, repairing, or otherwise maintaining the efficiency of an existing watercourse or drainage work'. For the Environment Agency this relates only to works in connection with a Main River. For IDBs and local authorities it relates only to works on, or in connection with, Ordinary Watercourses.

Main Rivers are watercourses shown on the statutory main river maps held by the Environment Agency and Defra (in England) and Natural Resources Wales and the Welsh Assembly Government (in Wales). They can include any structure or appliance for controlling or regulating the flow of water into, in or out of the channel.

An Ordinary Watercourse includes all rivers and streams and all ditches, drains, cuts, culverts, dikes, sluices, sewers (other than public sewers within the meaning of the Water Industry Act 1991) and passages, through which water flows, and which does not form part of a Main River.

The use of the above powers is discretionary, that is, the powers allow the Environment Agency/ IDB/ LLFA/ local authority to carry out the works it feels necessary or appropriate.

Under Schedule 25 of the **Water Resources Act 1991** and section 66 of the **Land Drainage Act 1991,** the Environment Agency and IDBs/ local authorities, respectively, may make byelaws to secure the efficient working of the drainage system within their district or area and also, as amended by the **Flood and Water Management Act 2010**, to regulate the effects on the environment of the drainage system within their district or area. Such byelaws differ between Environment Agency regions, and individual IDBs and local authorities; however, many include powers to serve notice on landowners/ occupiers to cut and remove vegetation growing in or on the bank of a Main River (Environment Agency byelaws) or watercourse (IDB and local authority byelaws) to prevent any obstruction or impediment to, or interference with, the flow of water into, in or out of the Main River or the watercourse.

A.1.2 Nature conservation

General conservation duties of the Environment Agency, IDBs and local authorities

The Environment Agency's duties with respect to flood risk management relate to conservation, public access and recreation. Under section 7 of the **Environment Act 1995** in formulating or considering any proposals relating to flood risk management so far as may be consistent with the purpose of the statutory provision, the Environment Agency must exercise its powers so as to further conservation.

Section 6 of the **Environment Act 1995** is quite specific regarding the Environment Agency's conservation duty. It states that the Environment Agency has a general duty to promote (to the extent it considers desirable):

1. The conservation and enhancement of the natural beauty and amenity of inland and coastal waters and of land associated with such waters
2. The conservation of flora and fauna which are dependent on an aquatic environment
3. The use of such waters and land for recreational purposes and in this respect the Agency should take into account the needs of persons who are chronically sick or disabled

The general environmental duties imposed upon the Environment Agency have been imposed on IDBs and local authorities via the **Land Drainage Act 1991** as amended by the **Land Drainage Act 1994**. The duties largely parallel the duties on the Environment Agency in respect of conservation, public access and recreation.

The **Land Drainage Act 1994** places a duty on IDBs and local authorities with respect to the environment and recreation to have regard to the natural and built environment and public access. Section 61 of the 1994 Act states that in discharging its functions with relation to land drainage, the IDB or local authority must further the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest. It is also required to have regard to the desirability of protecting and conserving buildings, sites and objects of archaeological, architectural or historic interest, and to take into account any effect which any proposals would have on the beauty or amenity of any rural or urban area, or on any such flora, fauna, features, buildings, sites or objects.

Biodiversity

Aquatic and riparian plant management may be required for nature conservation purposes, for example, to restore or enhance the habitat of a watercourse or a population of a species within a watercourse.

The **Natural Environment and Rural Communities (NERC) Act 2006** sets out Natural England's statutory purpose:

> 'to ensure that the natural environment is conserved, enhanced and managed for the benefit of present and future generations, thereby contributing to sustainable development'.

Section 40(1) of the **NERC Act 2006** imposes a duty on public authorities to conserve biodiversity:

> 'Every public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity.'

Section 40(3) of the **NERC Act 2006** explains that:

> 'Conserving biodiversity includes, in relation to a living organism or type of habitat, restoring or enhancing a population or habitat'.

The duty applies to a wide range of organisations including all local authorities, government departments, non-departmental public bodies (for example, the Environment Agency and IDBs), utilities and all other bodies carrying out functions of a public character under a statutory power. It extends beyond just conserving what is already there to carrying out, supporting and requiring actions that may also restore or enhance biodiversity.

Section 41 in relation to England and section 42 in relation to Wales of the **NERC Act 2006** requires the Secretary of State/ National Assembly of Wales to publish a list of habitats and species that are of principal importance for the conservation of biodiversity in England and Wales. The Section 41 list for England (including 56 habitats and 943 species) has been drawn up in consultation with Natural England and draws upon the UK Biodiversity Action Plan (BAP) List of Priority Species and Habitats. The Section 42 list for Wales includes 54 habitats, 557 species and four additional species groups/ assemblages and has also been drawn from the UK BAP List of Priority Species and Habitats.

When implementing their duty under section 40 of the **NERC Act 2006**, public authorities should have regard to these lists. The list includes a number of aquatic and riparian plant species which require sensitive management regimes to conserve and enhance their populations, for example, floating water-plantain *Luronium natans*, grass-wrack pondweed *Potamogeton compressus*, tubular water-dropwort *Oenanthe fistulosa* and greater water-parsnip *Sium latifolium*.

Sites of Special Scientific Interest (SSSIs)

SSSIs are legally protected under the **Wildlife and Countryside Act 1981**, as amended by the **Countryside and Rights of Way (CROW) Act 2000** and the **NERC Act 2006**.

This legislation gives Natural England and Natural Resources Wales power to ensure better protection and management of SSSIs and to safeguard their existence into the future. By 2020, the government's objective is to see that 50% of the total area of SSSIs is in a favourable condition, while at least 45% of the remaining area of SSSIs are in a stage of recovery and can be expected to reach favourable condition once management plans have taken effect.

Under section 28G of the **Wildlife and Countryside Act 1981** (as amended), a number of authorities – known as 'Section 28G authorities' and those to which section 40 of the **NERC Act 2006** also apply – have a duty to take reasonable steps, consistent with the proper exercise of their functions, to further the conservation and enhancement of the flora, fauna or geological or physiographical features by reason of which a site has been designated a SSSI. They also have specific duties under sections 28H and 28I in relation to carrying out and authorising operations likely to damage a SSSI.

Some SSSIs may require the management of aquatic and riparian plants to maintain or achieve favourable condition. This may include SSSIs where water levels and flow are critical to the site's condition, where non-native invasive species are having an adverse impact on the interest features of the site, and/ or where the interest features include certain aquatic and riparian plants that require management to maintain or enhance their populations. However, it should also be noted that the presence of SSSIs may also constrain aquatic and riparian plant management operations, as discussed in section A.3.

European designated sites

The Conservation of Habitats and Species Regulations 2010 (as amended) consolidate all the various amendments made to the **Conservation (Natural Habitats, &c.) Regulations 1994** in respect of England and Wales. The 1994 Regulations transposed **Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora** (Habitats Directive) and **Directive 79/409/EEC on the conservation of wild birds into national law** (Birds Directive).

European sites include Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), which together are known as 'Natura 2000' sites. SACs are strictly protected sites designated under the Habitats Directive.

Article 3 of the Habitats Directive requires the establishment of a European network of important high quality conservation sites that will make a significant contribution to conserving the 189 habitat types and 788 species identified in Annexes I and II of the Directive (as amended). The listed habitat types and species are those considered to be most in need of conservation at a European level (excluding birds). These listed habitats and species are described as 'Special Interest Features' and form the key focus of the Conservation Objectives of SAC sites, all of which are also SSSIs. The management of aquatic and riparian plants may therefore be required specifically to maintain or restore these features on European designated sites.

Two Annex I habitats which may be affected by the management of aquatic and riparian vegetation are:

- 3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

- 91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*

Further detail on the ecological characteristics and the status and distribution in England and Wales for these habitats is given in Table A.1.

Table A.1 Characteristics, status and distribution of Annex I habitats which may be affected by aquatic and riparian plant management

	3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation [1]	**91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)** [2]
Description	This habitat type is characterised by the abundance of Water-crowfoots *Ranunculus* spp. There are several variants (with three main sub types) of this habitat in the UK, depending on geology and river type. In each, water-crowfoot *Ranunculus* species are associated with a different assemblage of other aquatic plants.	This habitat type comprises woods dominated by Alder *Alnus glutinosa* and Willow *Salix* spp. on flood plains in a range of situations from islands in river channels to low-lying wetlands alongside the channels. The habitat typically occurs on moderately base-rich, eutrophic soils subject to periodic inundation.
Status and Distribution	The habitat type is widespread in rivers in the UK, especially on softer and more mineral-rich substrates. It is largely absent from areas underlain by acid rock types (principally in the north and west). It has been adversely affected by nutrient enrichment, and where agriculture has caused serious siltation. It is also vulnerable to artificial reductions in river flows and to unsympathetic channel engineering works. Consequently, the habitat has been reduced or has disappeared from parts of its range in Britain.	Clearance of riverine woodland has eliminated most true alluvial forests in the UK. Many surviving fragments, as elsewhere in Europe, are fragmentary and often of recent origin. Residual alder woods frequently occur in association with other woodland types or with other wetland habitats such as fens.
SACs for which the habitat is a primary reason for selection (England and Wales)	England: River Avon, Dorset River Axe River Eden River Itchen, Southampton River Lambourn River Tweed River Wensum Wales: Afon Gwyrfai a Llyn Cwellyn	England: Kennet Valley Alderwoods River Eden, Cumbria The Broads The New Forest West Dorset Alderwoods Wales: Coed y Cerrig

	3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation [1]	91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) [2]
	River Teifi River Dee and Bala Lake River Wye	Meirionnydd Oakwoods and Bat Site Llwyn
SACs where the habitat is present as a qualifying feature (England and Wales)	England: River Derwent, Yorkshire River Derwent and Bassenthwaite Lake, Cumbria River Kent, Cumbria River Mease Wales: Cleddau Rivers Meirionnydd Oakwoods and Bat Site River Usk	England: Breckland Calf Hill and Cragg Woods Cothill Fen Exmoor and Quantock Oakwoods Lower Derwent Valley Norfolk Valley Fens River Camel Wales: Cleddau Rivers Alyn Valley Woods Coedydd Aber Crymlyn Bog Drostre Bank Gower Ash Woods North Pembrokeshire Woodlands Rhos Goch

Notes: [1] http://jncc.defra.gov.uk/ProtectedSites/SACselection/habitat.asp?FeatureIntCode=H3260

[2] http://jncc.defra.gov.uk/ProtectedSites/SACselection/habitat.asp?FeatureIntCode=H91E0

A number of Annex II species may be affected by the vegetation management of designated sites including:

- floating water-plantain *Luronium natans*
- southern damselfly *Coenagrion mercuriale*
- Desmoulin's whorl snail *Vertigo moulinsiana*

- lesser whirlpool ramshorn snail *Anisus vorticulus*
- white-clawed crayfish *Austropotamobius pallipes*
- sea lamprey *Petromyzon marinus*
- brook lamprey *Lampetra planeri*
- river lamprey *Lampetra fluviatilis*
- Atlantic salmon *Salmo salar*
- bullhead *Cottus gobio*
- otter *Lutra lutra*

Non-native invasive species

As previously mentioned, aquatic and riparian vegetation management may be conducted specifically to eradicate or control the spread of a non-native invasive species.

The Convention on Biological Diversity arose from the UN Conference on Environment and Development held in Rio in 1992. As of 2000, 179 governments have signed up; signatories are committed to:

- take appropriate measures to conserve biological diversity
- ensure the sustainable use of biological resources
- promote the fair and equitable sharing of benefits arising from the utilisation of genetic resources

Article 8(h) of the Convention requires each contracting party, as far as possible and as appropriate to 'prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'.

The **Wildlife and Countryside Act 1981** (as amended) contains measures for preventing the establishment of non-native invasive species which may be detrimental to native wildlife, and prohibiting the release of animals and the planting of species listed in Schedule 9, which includes riparian species such as Japanese knotweed *Fallopia japonica*, Himalayan balsam *Impatiens glandulifera* and giant hogweed *Heracleum mantegazzianum* together with aquatic species such as water fern *Azolla filiculoides* and floating pennywort *Hydrocotyle ranunculoides*. It is not an offence to have these species growing on your land, but it is an offence to cause them to spread onto adjacent land. The responsibility of dealing with non-native invasive plant species rests with individual landowners. Strategic widespread control is currently not the sole responsibility of any statutory organisation. Further details on the constraints to management posed by non-native invasive species are provided in section A.3.

In January 2013, to help curb the spread and to reduce the threat of non-native invasive species, an amendment was passed under the **Wildlife and Countryside Act 1981** to ban from sale five aquatic species – water fern *Azolla filiculoides*, parrot's-feather *Myriophyllum aquaticum*, floating pennywort *Hydrocotyle ranunculoides*, water-primrose *Ludwigia* spp. and Australian swamp stonecrop *Crassula helmsii.* This ban came into effect in April 2014 under the **Wildlife and Countryside Act 1981 (Prohibition on Sale etc. of Invasive Non-native Plants) (England) Order 2014** and may reduce the occurrence of these problematic species in the wild and therefore the need to manage them. However, given that these species are already successfully established and widespread throughout the UK the impact of this ban on management needs may take some considerable time to be realised.

A.1.3 Ecological improvement

The **Water Framework Directive (WFD)** came into force on 22 December 2000 and was transposed into national law in England and Wales in 2003 by the **Water Environment (Water Framework Directive) (England and Wales) Regulations 2003**. Its purpose is to establish a framework for the protection of water bodies (including lakes, streams and rivers), groundwaters and dependent ecosystems, estuaries and coastal waters. This framework aims to:

- prevent deterioration in the status of aquatic ecosystems, protect them and improve the ecological condition of waters
- achieve at least good ecological status (GES)/ good ecological potential (GEP) for all water bodies by 2015 and, where this is not possible, aim to achieve GES/ GEP by 2021 or 2027
- promote sustainable use of water as a natural resource
- conserve habitats and species that depend directly on water
- progressively reduce or phase out the release of individual pollutants or groups of pollutants that present a significant threat to the aquatic environment
- progressively reduce the pollution of groundwater and prevent or limit the entry of pollutants
- contribute to mitigating the effects of floods and droughts

To implement the Water Framework Directive, the Environment Agency has developed river basin management plans (RBMPs) throughout England and Wales. These are plans for protecting and improving the water environment. They describe the main issues for the water environment within each river basin district, set environmental objectives for each body of water and provide summaries of programmes of measures/ environmental improvements required to reach GES/ GEP.

While GES is defined as a slight variation from undisturbed natural conditions in natural water bodies, artificial water bodies (AWBs) and heavily modified water bodies (HMWBs) are unable to achieve natural conditions. These are water bodies that have been altered through human activity (for example, by flood risk management, urbanisation, land drainage and navigation). Instead, AWB/ HMWBs have a target to achieve GEP, which recognises their important uses, while making sure ecology is protected as far as possible. Aquatic and riparian plant management is most likely to be undertaken most frequently in artificial or heavily modified water bodies.

Specific mitigation measures/ environmental improvements have been identified for each AWB/ HMWB and are listed in the RBMP. These mitigation measures/ environmental improvements are necessary to reduce the existing ecological and hydromorphological impacts on the water body and all measures need to be in place in order for the water body to achieve GEP. Mitigation measures/ environmental improvements identified within RBMPs and relevant to aquatic and riparian plant management include:

- minimise disturbance to channel bed and banks
- manage vegetation appropriately
- sensitive techniques for managing vegetation

- sensitive timing of vegetation management
- manage invasive species

More information on these environmental improvements is given on the Healthy Catchments website (http://www.restorerivers.eu/RiverRestoration/Floodriskmanagement/HealthyCatchmentsmanagingforfloodriskWFD/tabid/3098/Default.aspx).

A.2 Legislation with regard to the implementation of vegetation management techniques

The legislation pertaining to the management of aquatic and riparian vegetation aims to ensure that operations are carried out safely, with minimal risks to the operators, members of the public and the environment.

The main legislative acts and responsibilities which must be considered when implementing aquatic and riparian plant management are summarised in Figure A.2 and described in the following sections.

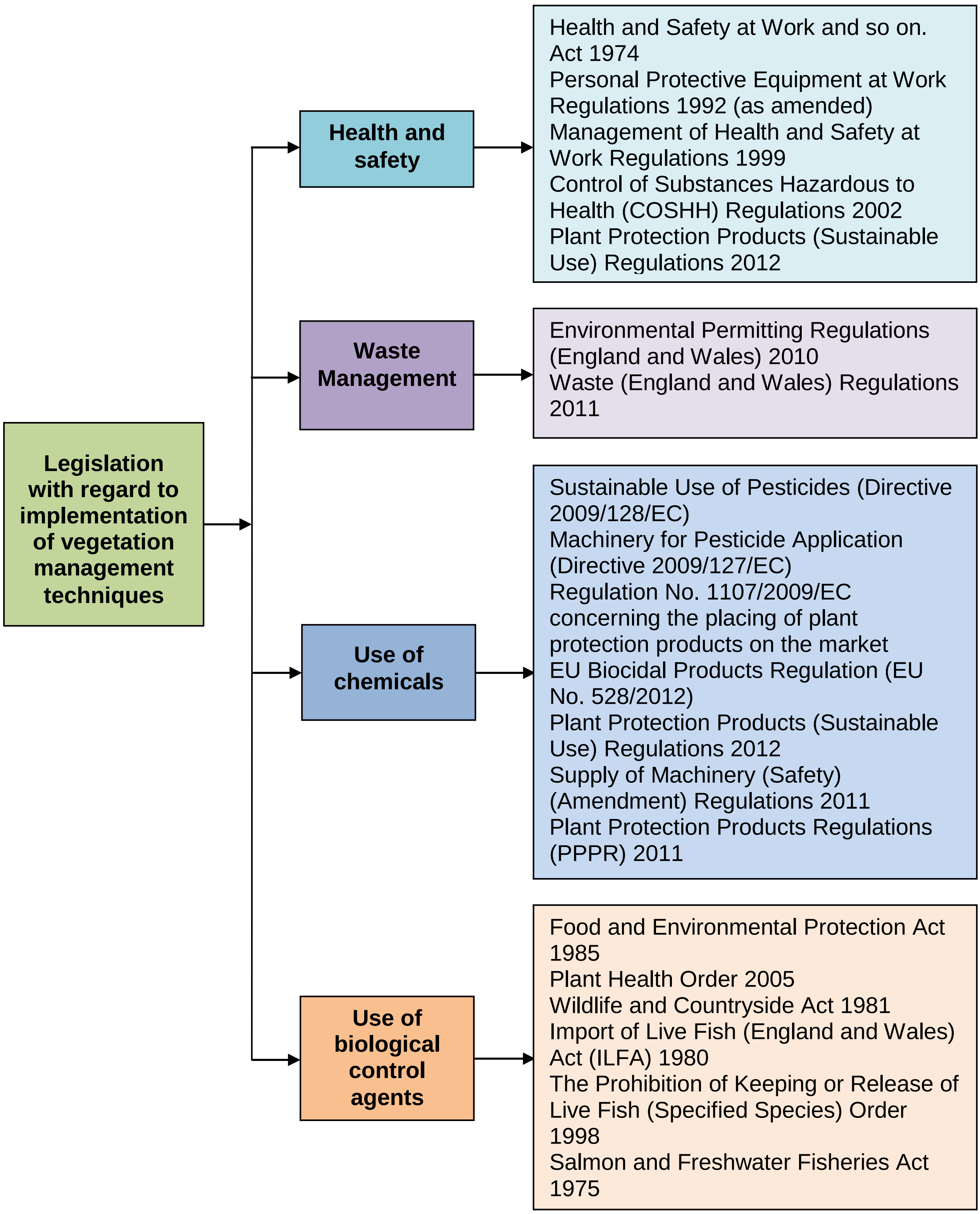

Figure A.2 Legislation with regard to the implementation of vegetation management techniques

A.2.1 Health and safety

The Health and Safety at Work etc. Act 1974 sets out the general duties of employers towards their employees and members of the public, and the duties employees have to themselves and to each other. Employers are required to ensure, so far as is reasonably practicable, the health safety and welfare at work of their employees, and any other persons who might be affected; provide a safe working environment; health and safety training, instruction and supervision; and any necessary protective clothing and equipment. The **Personal Protective Equipment at Work Regulations 1992 (as amended)** were created under the above act and place a duty on every employer to ensure that suitable PPE is provided to employees who may be exposed to a risk to their health or safety while at work.

The Management of Health and Safety at Work Regulations 1999 require employers to carry out suitable and sufficient assessments of risk to employees and others who might be affected by work activities, and to put in place appropriate risk control measures. Consequently, all aspects of the work will need to be considered during the risk assessment process including the hazards presented by working on or near water.

Any workplace on or near water presents a danger that people might slip or fall into the water. Adverse weather is also a factor that can increase the danger, and work conditions can change quickly. Whether or not a person is injured by falling in the water, there is an immediate risk of drowning and/ or being carried away by currents. It is essential, when working on or near water, that safe systems of work are in place based on a thorough risk assessment and that staff are properly trained and instructed.

When working on or near water consideration must also be given to the health implications of falls into the water. The water may possibly be polluted, for example, when working near sewage discharge points, and there is a risk of contracting leptospirosis (or Weil’s disease) from water contaminated by rat urine.

Substances which may cause harm to health are subject to the **Control of Substances Hazardous to Health (COSHH) Regulations 2002**, which place a legal duty on employers to prevent, or if this is not reasonably practicable, adequately control, employees’ exposure to hazardous substances (which includes many herbicides). A COSHH risk assessment must be carried out before herbicide application is made to assess any risks to operators and the general public. Any protective clothing that is required for the handling and use of the herbicide will be stipulated on the product label and must be worn. Information relating to first aid and medical treatment in the event of accidental exposure to the chemical is also given on the product label.

Under the **Plant Protection Products (Sustainable Use) Regulations 2012** the operative doing the spraying must hold a certificate of technical competence for herbicide use, or work under the direct supervision of a certificate holder, unless operating under ‘grandfather rights’ (this exemption will cease to apply from November 2015). Additionally, for spraying in or near water, the operative carrying out or supervising the spraying must have the appropriate aquatic part of the qualification.

A.2.2 Waste management

Aquatic plant material must be dealt with in accordance with the **Environmental Permitting Regulations (England and Wales) 2010 (as amended).** Under these regulations, exemptions must be registered, or permits applied for, with regards to waste operations. The Environment Agency (in England) and Natural Resources Wales (in Wales) are responsible for issuing permits and exemptions. The following exemptions, relating to the spreading of waste plant material on land and the depositing of dredging, are the most applicable to the management of aquatic and riparian vegetation within and adjacent to watercourses.

- **U13 Spreading of plant matter to confer benefit.** This exemption allows for the spreading of non-hazardous plant matter that is strimmed along the banks of the watercourse where it has been cut. This exemption is only for spreading plant matter at the place of production where benefit is conferred and for the spreading of up to 50 tonnes per hectare of waste in any 12-month period.

- **U10 Spreading waste on agricultural land to confer benefit.** This exemption allows for the spreading on agricultural land of non-hazardous dredging spoil generated from the creation or maintenance of habitats, ditches or ponds within parks, gardens, fields and forests. The maximum quantity of spoil allowed to be spread after dredging is 150 tonnes per hectare over a 12-month period. The waste must be spread adjacent to the place from which it was dredged and must confer benefit.
- **U11 Spreading waste on non-agricultural land to confer benefit**. This exemption allows for the spreading on non-agricultural land of non-hazardous dredgings from the creation or maintenance of habitats, ditches or ponds within parks, gardens, fields and forests. The waste must be spread adjacent to the place from which it was dredged and must confer benefit.
- **D1 Deposit of waste from dredging of inland waters.** This exemption allows for the deposit of non-hazardous dredging spoil (dredgings, which also includes plant matter) on the banks of the waters it was dredged from and to treat it by screening and de-watering. Over any 12-month period, the exemption allows for the depositing or treating of up to 50 m^3 of dredgings for each metre of land on which waste is deposited. The waste must be deposited at the closest possible point to where it was dredged from – either on the bank of, or on land adjoining, the water it was dredged from, as long as it can be deposited on that land by mechanical means in one operation. This means that it is not permitted to deposit dredged material onto a bank and then move it further away by the same or another machine. The equipment used should be able to take the dredgings from the watercourse and move it to that land in one move.
- Other exemptions which may also apply in certain situations include the following.
- **T23 Aerobic composting and associated prior treatment.** This exemption allows for the composting of small volumes of vegetation to produce a compost that can be spread on land to provide benefit.
- **T25 Anaerobic digestion at premises not used for agriculture and burning of resultant biogas.** This exemption allows the treatment of plant tissue waste and other biodegradable wastes by anaerobic digestion to produce a digestate which can be used to provide benefit to land. The gas produced must be used for generating energy.
- **D7 Burning waste in the open.** This exemption allows for the burning of plant tissue and untreated wood wastes in the open. Waste can only be burnt at the place where it was produced.

Under the **Environmental Permitting Regulations (England and Wales) 2010 (as amended),** if cut vegetation is not removed from the water, the disposal of this vegetation within water becomes a water discharge activity and requires an environmental permit or the registering of an exemption.

If waste has to be removed from site it must be transferred to an authorised person, who is either a registered carrier or exempted from registration by the **Waste (England and Wales) Regulations 2011**. A waste transfer note must be completed and signed giving a written description of the waste as per regulation 35.

A.2.2 Use of chemicals

Within the UK, the chemical control of aquatic and riparian vegetation is regulated and underpinned by a range of legislation, much of it giving effect to EU requirements. The relevance to this project varies, however legislation that may apply include the following.

- The Plant Protection Products (Sustainable Use) Regulations 2012, which transpose Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides. This directive provides a framework to reduce risks and impacts of pesticide use on human health and the environment. See also the UK national implementation plan for the sustainable use of pesticides (plant protection products), which was published on 26 February 2013.
- Regulation No. 1107/2009/EC concerning the placing of plant protection products on the market. This regulation repealed and replaced Directive 91/414/EEC and aims to ensure a high level of human, animal and environmental protection, as well as harmonising, as far as possible, the overall arrangements for authorisation of plant protection products within the EU, setting common rules and guidance on data requirements; data evaluation; risk assessment; the protection of commercial information (data protection); and public access to information on pesticides. Plant protection products include herbicides/ weedkillers intended to destroy undesired plants or parts of plants or to check or prevent undesired growth of plants ('plants' excludes algae unless the products are applied on soil or water to protect plants).
- Directive 2006/42/EC (as amended by Directive 2009/127/EC) with regard to machinery for pesticide application. This directive sets requirements for the inspection and maintenance of machinery for pesticide application, given that the design construction and maintenance of the machinery can have a significant role in reducing the adverse effects of pesticides on human health and the environment. The amendments to the Directive were brought into force in the UK on 15 December 2011, through the Supply of Machinery (Safety) (Amendment) Regulations 2011.
- EU Biocidal Products Regulation (EU No. 528/2012) replacing Directive 98/8/EC concerning the placing of biocidal products on the market. This regulation aims to harmonise the European market for biocidal products and their active substances, while providing a high level of protection for humans, animals and the environment.

The most important UK legislation potentially impacting on the chemical control of aquatic and riparian vegetation is summarised below.

Herbicide use

The **Plant Protection Products Regulations (PPPR) 2011 (as amended)** provide for the enforcement of Regulation No. 1107/2009/EC concerning the placing of plant protection products on the market in Great Britain.

The **Plant Protection Products (Sustainable Use) Regulations 2012** transpose Directive 2009/128/EC on the sustainable use of pesticides in the UK as regards storing and using plant protection products. The key provisions of the implementing legislation, developed to help transpose the directive, which are relevant to aquatic and riparian plant management are that:

- users be trained and hold a training certificate provided by a designated training body
- application equipment is tested and certificated by a designated testing body in accordance with the timescales set out in the regulations

- all reasonable precautions are taken to protect human health and the environment when storing, using, handling and disposing of pesticides, their remnants and packaging and cleansing of machinery
- use is minimised certain protected areas designated under the Water Framework Directive and the EU Habitats and Birds Directives
- as far as is reasonably practicable, preference should be given to products not classified as dangerous for the aquatic environment nor containing priority hazardous substances

Within the UK pesticides, including herbicides, must be authorised under the above regulations by the Chemicals Regulation Directorate (CRD) before they can be sold and supplied for use.

Further information on the use of pesticides, including herbicides, can be found within *Code of Practice for Using Plant Protection Products* (Defra 2006) and an associated code relating to storage practice. These codes cover a range of issues including emergency procedures, storage, application and disposal. The codes have not yet been updated to reflect the requirements of the **Plant Protection Products (Sustainable Use) Regulations 2012**, and so should be read in conjunction with guidance provided by the Health and Safety Executive. A new combined code is expected to be issued in mid-2014 (G. Stark, personal communication).

The use of herbicides to control plants in water or on the banks or banksides next to a watercourse or other body of water requires agreement from the Environment Agency. This is to make sure that the proposed use of the herbicide could not damage or pollute the aquatic environment (including both surface water and groundwater).

Adjuvants

Adjuvants are substances, other than water, added to enhance the effectiveness of a plant protection product (for example, extenders, wetting agents, sticking agents or fogging agents) (Britt et al. 2003). Adjuvants are authorised under European legislation Regulation (EC) No. 1107/2009 (discussed above). However, under Article 81(3) of Regulation No. 1107/2009 there is a derogation stating that Member States may apply national provisions for authorisation of adjuvants until the adoption of detailed rules referred to in Article 58(2). This provision is implemented in Great Britain by Schedule 2 of the **Plant Protection Products (Sustainable Use) Regulations 2011**. This schedule states that an adjuvant is authorised for use with an authorised plant protection product if it is included in a published list of adjuvants or, if not included in the list, if it is used with an authorised plant protection product for the sole purpose of research and development. CRD maintains the published list of adjuvants.

Within the UK, the CRD does not currently regulate other types of spray additives such as dyes, markers, carriers, anti-transpirants or anti-foaming agents.

Biocides

The **EU Biocidal Products Regulation (EU No. 528/2012)** came into force on 1 September 2013. It revises and replaces the current regulatory framework for the marketing and use of biocidal products contained in the Biocidal Products Directive (98/8/EC). This regulation covers a very diverse group of products, including disinfectants, pest control products and preservatives, not included in the legislation that covers pesticides discussed above. Specifically, a biocidal product is defined as:

> ‘...an active substance or a preparation containing one or more active substances, in the form in which it is supplied to the user, intended to destroy, deter, render harmless, prevent the action of, or otherwise exert a controlling effect on, any harmful organism by chemical or biological means’.

In this instance an ‘active substance’ is a substance or micro-organism which has a general or specific action on or against harmful organisms. Therefore, control of a harmful organism by ‘chemical means’ is linked to the interference of that substance in biological/ physiological processes through direct chemical interaction (inside or outside the target organisms) or indirect modifications because of the physical/ chemical properties of the substance. However, control by biological means is considered to occur when the control action directly involves living micro-organisms.

Biocides cover a very diverse group of products, but not those already regulated under certain other European legislation such as that pertaining to plant protection products. There is obviously considerable overlap between legislation governing pesticides and biocides.

A.2.3 Use of biological control agents

Non-native animals cannot be released for biological control purposes unless a licence has been granted, whether or not they will be commercially distributed. Organisms which are potentially harmful to plants and which do not normally occur in Great Britain are regulated by the **Plant Health Order 2005**. Controls on the import of invertebrate plant pests listed on Schedules 1 and 2 of the Order require that they cannot be imported to Britain without a licence. The granting of a licence is conditional upon the findings of a Pest Risk Assessment.

The use of non-native biological control agents is bound by the United Nations Food and Agriculture Organization (FAO) *Code of Conduct for the Import and Release of Exotic Biological Control Agents* (International Standards for Phytosanitary Measures (ISPM) No. 3), which was adopted in 1996. Although primarily aimed at protecting crops, it is regarded as the general international protocol for countries implementing biological control. The European and Mediterranean Plant Protection Organisation (EPPO) has also developed standards (PM6)5 to provide guidelines for assessing and reducing risks associated with biological control agents and, in some cases, for comparing their efficacy. The Organisation for Economic Co-operation and Development (OECD) has developed guidance on information requirements for ecological risk analysis. But although both these focus on commercial invertebrate biological control agents, they are advisory and not regulatory documents.

Releases of non-native species can be licensed under section 16 of the **Wildlife and Countryside Act 1981**. An offence under section 14 is avoided if a release was carried out in accordance with the terms and conditions of a licence granted by the appropriate authority. The appropriate authority is the Food and Environment Research Agency (FERA) in England and Natural Resources Wales in Wales. Licences are issued on a case-by-case basis after consultation with the appropriate statutory conservation bodies and the Advisory Committee on Releases to the Environment (ACRE).

Section 16 licences may be:

- general or specific
- granted to a particular person or to a class of persons
- subject to any specified conditions

- modified or revoked at any time by the licensing authority

Grass carp

In England and Wales, the introduction of non-native grass carp *Ctenopharyngodon idella* into the wild requires a licence under the **Import of Live Fish (England and Wales) Act (ILFA) 1980**. This Act gives the Minister the power to make Orders to prohibit or licence the import, keeping or release of non-native fish species which might harm the habitat of, compete with or prey on any freshwater fish, shellfish or salmon. **The Prohibition of Keeping or Release of Live Fish (Specified Species) Order 1998**, made under the ILFA in England and Wales, prohibits the unlicensed keeping or release of 26 species or genera of non-native fish, including grass carp.

To release grass carp a licence is also required under section 16 of the **Wildlife and Countryside Act 1981**, as described above, and Environment Agency consent under section 30 of the **Salmon and Freshwater Fisheries Act 1975** (as amended by the **Environment Act 1995**).

A.3 Environmental considerations

Aquatic and riparian plant management has the potential to impact upon the environment and these impacts must be assessed prior to the implementation of a particular management technique or method. The following sections describe the main environmental legislative acts and responsibilities which must be considered.

A.3.1 European designated sites

The Conservation of Habitats and Species Regulations 2010 (as amended) provide for the designation and protection of ‘European sites’, the protection of ‘European Protected Species’ (EPS), and the adaptation of planning and other controls for the protection of European sites.

European sites include the Natura 2000 sites (SPAs and SACs). These sites tend to cover large areas, often consisting of a number of smaller separate but related SSSIs. Aquatic and riparian plant management within or adjacent to sites designated as SACs and SPAs has the potential to adversely impact on the integrity of the interest features for which they are designated. Assessments must be conducted, in conjunction with Natural England and Natural Resources Wales, to determine if significant effects are likely. If likely significant effects are identified, mitigation measures will need to be devised and implemented.

For some SACs, particularly those associated with rivers and ditches, Natural England/ Natural Resources Wales may require specific vegetation management plans/ guidance to be followed which define the type/ amount/ frequency/ timing of management required to meet the conservation objectives for the site and contribute towards achieving favourable conservation status of the features.

A.3.2 SSSIs

As discussed in section A.1.2, section 28G of the **Wildlife and Countryside Act 1981 (as amended)** requires a number of authorities to take reasonable steps, consistent with the proper exercise of their functions, to further the conservation and enhancement of the flora, fauna or geological or physiographical features by reason of which a site has been designated a SSSI. This frequently provides a driver to aquatic and riparian plant management.

However, the presence of SSSIs can also constrain the management of aquatic and riparian vegetation in some instances, potentially compromising the requirements of other watercourse functions (for example, flood risk management). For example, the management of a designated watercourse, which is usually agreed in writing with Natural England or Natural Resources Wales, may require incorporation of practices or timing restrictions that would not apply in non-designated watercourses. Consent may be required from Natural England or Natural Resources Wales for any aquatic and riparian plant management techniques that could damage the special interest of a designated site.

The **Countryside and Rights of Way (CROW) Act 2000** strengthens the legal protection given to SSSIs under the **Wildlife and Countryside Act 1981**. It provides increased powers for the protection and management of SSSIs and places a duty on public bodies, through amendments to section 28G of the Wildlife and Countryside Act 1981, to further the conservation and enhancement of SSSIs, as described above.

A.3.3 Protected species

European protected species are animals and plants listed in Annex IV of the **EC Habitats Directive** and protected under the **Conservation of Habitats and Species Regulations 2010 (as amended)**. This list includes bats, otter *Lutra lutra*, great crested newt *Triturus cristatus* and floating water-plantain *Luronium natans*.

For animal species it is an offence to:

- deliberately capture, injure or kill any wild animal of a European protected species
- deliberately disturb wild animals of any such species
- deliberately take or destroy the eggs of such an animal
- damage or destroy a breeding site or resting place of such an animal

These offences apply to all stages of the animal's life

For plant species it is an offence to deliberately pick, collect, cut, uproot or destroy a wild plant of an European protected species.

Aquatic and riparian plant management therefore has the potential to impact on species which inhabit aquatic and riparian environments, such as otter *Lutra lutra* or floating water-plantain *Luronium natans*. In some cases management will need to be planned, in consultation with Natural England or Natural Resources Wales (which may issue a licence), to ensure that these species are not adversely impacted.

Additionally, the **Wildlife and Countryside Act 1981 (as amended**) also provides protection to a number of species that could potentially be adversely impacted by aquatic and riparian vegetation management, as outlined below. Under section 1 of the Act it is an offence (with exception to species listed in Schedule 2) to intentionally:

- kill, injure or take any wild bird
- take, damage or destroy the nest of any wild bird while that nest is in use or being built
- take or destroy an egg of any wild bird

This therefore places a constraint on aquatic and riparian vegetation management, as in many locations this vegetation provides ideal habitat for nesting waterfowl (for example, moorhen *Gallinula chloropus*, mallard *Anas platyrhynchos*) and a number of wetland songbirds (for example, reed bunting *Emberiza schoeniclus* and sedge warbler *Acrocephalus schoenobaenus*). Management by physical means, such as flail mowing and de-weeding, could damage and/ or destroy nests, which would be an offence. Therefore it is important that vegetation management takes into account the presence of nesting birds.

In addition, more easily disturbed and rarer species (for example, kingfisher *Alcedo atthis*) are listed on Schedule 1 of the Act, receiving additional protection from disturbance while they have dependent young, even if away from the nest. In locations where these Schedule 1 species are found, then these place an additional constraint on the management of aquatic and riparian vegetation.

This Act also makes it an offence (subject to exceptions) to intentionally kill, injure or take any wild animal listed on Schedule 5, and prohibits interference with places used for shelter or protection, or intentionally disturbing animals occupying such places. Animals listed on Schedule 5 which may be impacted upon by physical methods of aquatic and riparian vegetation management include water vole *Arvicola amphibius*, otter *Lutra lutra*, great crested newt *Triturus cristatus*, reptiles and white-clawed crayfish *Austropotamobius pallipes*. Impacts could be through the removal of habitat from the aquatic and riparian zone, or actual killing or injuring of individual animals by machinery. If it is thought that proposed works are likely to result in an offence then the following actions should be carried out:

- surveys for the presence of protected species prior to the planning of works
- if required, modifying the proposed work as a result of the survey to avoid an offence being committed
- training of staff and/ or contractors undertaking the work
- appropriate mitigation measures and working practices to be applied during the work

The Act also makes it an offence (subject to exceptions) to intentionally pick, uproot or destroy any wild plant listed in Schedule 8. Plants included on this list which may occur in watercourses include floating water-plantain *Luronium natans* and triangular club-rush *Schoenoplectus triqueter*.

The Act also provides a mechanism making any of the above offences legal through the granting of licences by the appropriate authorities.

The Countryside and Rights of Way Act 2000 strengthens the legal protection for threatened species. The provisions make certain offences ‘arrestable’, create a new offence of reckless disturbance, confer greater powers to police and wildlife inspectors, and enable heavier penalties on conviction of wildlife offences.

The setts of badgers *Meles meles* are often found alongside watercourses and therefore aquatic and riparian plant management has the potential to adversely impact upon them. Badgers and their setts are protected under the **Protection of Badgers Act 1992**, which makes it an offence to:

- wilfully kill, injure, take, possess, or cruelly ill-treat a badger
- attempt to damage or destroy a sett
- attempt to obstruct access to, or any entrance of, a badger sett
- attempt to disturb a badger when it is occupying a sett

A badger sett is defined as ‘any structure or place which displays signs indicating current use by a badger’. Therefore, undertaking physical or environmental methods of aquatic and riparian plant management could adversely impact on this species.

There is provision within the legislation for licenses to be granted for works in the proximity of badger setts to:

- maintain or improve any existing watercourse or drainage works
- construct new works required for the drainage of any land

The undertaking of aquatic vegetation control, particularly by mechanical methods, could result in damage and/ or disturbance to fish and their spawning grounds. Spawning fish are protected under the **Salmon and Freshwater Fisheries Act 1975**. Under section 12 of the Act any person who, except in the exercise of a legal right to take materials from any waters, wilfully disturbs any spawn or spawning fish, or any bed, bank or shallow on which any spawn or spawning fish may be, shall be guilty of an offence. Additionally, under section 4, any person who causes or knowingly permits to flow, or puts or knowingly permits to be put, into any waters containing fish or into any tributaries of waters containing fish, any liquid or solid matter to such an extent as to cause the waters to be poisonous or injurious to fish or the spawning grounds, spawn or food of fish, shall be guilty of an offence.

A.3.4 Non-native species

While non-native invasive species may act as a driver for aquatic and riparian plant management, as discussed in section A.1.2, they may also constrain certain activities and therefore require consideration during the planning of any vegetation management operations. The **Wildlife and Countryside Act 1981 (as amended)** contains measures for preventing the establishment of non-native invasive species which may be detrimental to native wildlife. It is an offence if any person plants or otherwise causes to grow in the wild any plant which is included in Part II of Schedule 9. Species listed on Part II of Schedule 9 includes bankside species such as Japanese knotweed *Fallopia japonica*, Himalayan balsam *Impatiens glandulifera* and giant hogweed *Heracleum mantegazzianum*, along with a number of aquatic species including:

- fanwort *Cabomba caroliniana*
- water fern *Azolla filiculoides*
- water hyacinth *Eichhornia crassipes*
- water lettuce *Pistia stratiotes*
- parrot’s-feather *Myriophyllum aquaticum*
- floating pennywort *Hydrocotyle ranunculoides*
- duck potato *Sagittaria latifolia*
- floating water-primrose *Ludwigia peploides*
- water-primrose *Ludwigia grandiflora* and *L. Uruguayensis*
- Australian swamp stonecrop (also known as New Zealand pigmyweed) *Crassula helmsii*
- curly waterweed *Lagarosiphon major*
- all waterweed species of the waterweed genus *Elodea*

It is not an offence to have these species growing on your land, but it is an offence to cause them to spread onto adjacent land.

Furthermore, it is also an offence to release or allow to escape into the wild any animal listed on Part I of Schedule 9. This includes Chinese mitten crab *Eriocheir sinensis*, signal crayfish *Pacifastacus leniusculus* and several other non-native crayfish species and American mink *Neovison neovison* which may be encountered during management of aquatic and riparian vegetation.

The presence of certain non-native invasive species may constrain certain management operations, for example, through restricting access. Management could potentially indirectly result in the spread of a non-native invasive plant species, necessitating implementation of an appropriate biosecurity strategy.

The **Environmental Protection Act 1990** has very limited provisions for non-native species, but is included here due to the potential classification of soil and other waste containing viable propagules of invasive non-native plant species as controlled waste. This has been applied to Japanese knotweed *Fallopia japonica* and giant hogweed *Heracleum mantegazzianum*, with the result that waste containing these species must be disposed of in accordance with Environment Agency guidance designed to prevent the further spread of the plant.

A.3.5 Weed species

Under the **Weeds Act 1959** the Secretary of State for the Environment, Food and Rural Affairs can, if satisfied that injurious weeds are growing upon any land, serve a notice requiring the occupier to take action to prevent the spread of those weeds. An unreasonable failure to comply with a notice is an offence. The Weeds Act applies to:

- common ragwort *Senecio jacobaea*
- spear thistle *Cirsium vulgare*
- creeping thistle *Cirisium arvense*
- curled dock *Rumex crispus*
- broad-leaved dock *Rumex obtusifolius*

The **Natural Environment and Rural Communities Act 2006** delegates the functions available to the Secretary of State under the Weeds Act to Natural England. This delegation of functions enables Natural England to investigate complaints where there is a risk that injurious weeds might spread to neighbouring land. Natural England gives priority to investigating complaints where there is a risk of weeds spreading to land used for grazing horses or livestock, land used for forage production and other agricultural activities.

These species may be present on the banks of watercourses and therefore the control of riparian vegetation, particularly by mechanical methods, could increase the risk of spread of these species.

A.3.6 Pollution

The **EU Nitrates Directive**, implemented in England via the **Nitrate Pollution Prevention Regulations 2008 (as amended)**, was introduced to combat nitrate pollution. The directive requires Nitrate Vulnerable Zones (NVZs) to be established in polluted catchments where nitrate from agricultural land is causing pollution to water sources. Action plans are then developed to reduce pollution. Large proportions of lowland England are designated as NVZs and are subject to rules regulating the amount of nitrogen and nitrogen containing compounds which can be applied to the land. While the rules are complex, the general rule is that the quantity of nitrogen applied to the land shall not exceed that required by the growing crops. Dredged materials and weed cuttings can contain significant quantities of nitrogen and their application to lands, even alongside the banks of watercourses, can cause an increase in nitrogen levels and the impacts of this in relation to conducting aquatic and riparian plant management need to be considered.

The former **Groundwater Directive (80/68/EEC)** targeted the prevention of groundwater pollution via controls over the release of substances listed within it. This directive has been effectively superseded by the Water Framework Directive and in particular the **Groundwater Daughter Directive (2006/118/EC)** and its transposition in England and Wales are now via the **Environmental Permitting Regulations (England and Wales) Regulations 2010 (as amended)**.

Serious incidents of groundwater pollution due to pesticides are rare; they make up less than 1% of recorded pollution incidents. However, when they do occur they can cause severe environmental damage. Where there are imminent threats and actual cases of damage, the **Environmental Damage (Prevention and Remediation) Regulations 2009** require that those responsible must take immediate action to prevent damage occurring or remediate damage where it does occur. Also, under the **Environmental Permitting Regulations (England and Wales) Regulations** 2010 (as amended) it is an offence to cause or knowingly permit a groundwater activity unless complying with an environmental permit or exemption.

The CRD's responsibilities include the regulation of plant protection products and biocides (including pesticides). The Biocides Directive and the Plant Protection Products Directive (and Regulation) require companies that currently produce or develop new pesticides to submit them to an approval process. The risk of groundwater pollution is a factor in the approval process and may mean that conditions on use are applied or, in high-risk cases, lead CRD to refuse approval.

A.3.7 Historic environment

Section 2(2) of the **Ancient Monuments and Archaeological Areas Act 1979** states that consent must be obtained for any flooding or tipping operations on land in, on or under which there is a scheduled monument. Therefore, the presence of a scheduled monument immediately adjacent to a watercourse could constrain the depositing of any plant material removed from the watercourse, or any works which modify the bank or bed and could result in damage to the monument.

A.3.8 Assessment of environmental impacts

Some environmental plant management techniques, for example, modifications to the channel (that is, widening, narrowing, deepening, installation of structures) to alter flow characteristics may fall under the **Environmental Impact Assessment (EIA) (Land Drainage Improvement Works) Regulations 1999 (as amended).** Under these regulations drainage bodies (that is, Environment Agency, IDBs, LLFAs and local authorities) are required to determine whether 'improvement works' will have a significant impact on the environment.

The Regulations define 'improvement works' as:

> 'works which are –

(a) the subject of a project to deepen, widen, straighten or otherwise improve or alter any existing watercourse or remove or alter mill dams, weirs or other obstructions to watercourses, or raise, widen or otherwise improve or alter any existing drainage work; and

(b) permitted development by virtue of Part 14 or 15 of Schedule 2 to the Town and Country Planning (General Permitted Development) Order 1995.'

Maintenance works are not covered by the EIA regulations. This means, for example, that activities such as de-weeding, flailing and other operations where the hard bed or banks are not excavated do not require an EIA. However, dredging that includes excavation of the hard bed material (that is, creating a larger channel) does require an EIA if there are likely to be significant environmental effects (MAFF 2000).

Land drainage improvement works undertaken by drainage bodies are 'permitted development' under the **Town and Country Planning (General Permitted Development) Order 1995** and are therefore exempt from planning permission. As such works may have significant effects on the environment, the principles of environmental impact assessment need to be applied to them.

However, for European sites (SACs and SPAs), existing provisions within the **Town and Country Planning (General Permitted Development) Order 1995** and the **Conservation of Habitats and Species Regulations 2010 (as amended)** are designed to ensure that permitted developments likely to have a significant effect on a European site cannot go ahead unless the local planning authority has determined, after consultation with Natural England, that the development would not affect its integrity.

A.3.9 Hydromorphological impacts

As discussed in section A.1.3, the management of aquatic and riparian vegetation can contribute towards the delivery of **Water Framework Directive** objectives and targets. However, if management techniques are undertaken in a manner that causes a deterioration in the ecological status of a water body, this may lead to a water body failing to meet its WFD objectives and could lead to enforcement action being taken against the person who did the work, or alternatively, if the works were consented, then enforcement action against the consenting organisation.

Therefore, before undertaking any aquatic and riparian plant management, the ecological and hydromorphological impacts of the management technique to be used will need to be fully assessed to establish if it will cause deterioration or prevent the achievement of ecological objectives.

To implement the requirements of the Water Framework Directive, certain provisions of the **Water Resources Act 1991** were amended by the **Water Resources Act 1991 (Amendment) (England and Wales) Regulations 2009**. For any works/ activities undertaken without flood defence consent, section 161ZA provides the Environment Agency with the power to remediate any adverse effects on water bodies caused by damage to any hydromorphological quality element that would likely prevent the achievement of its WFD objectives.

A.4 Other permissions and consents

Management techniques which result in physical modifications to the channel or banks (for example, deepening and widening, or the installation of structures) to alter flow rates and water depth will require consent from the Environment Agency/ Natural

Resources Wales (if the watercourse is a Main River) under section 109 of the Water Resources Act 1991 or the IDB/ LLFA (if it is an Ordinary Watercourse) under section 23 of the Land Drainage Act 1991. Under these Regulations the Environment Agency/ Natural Resources Wales, IDBs and LLFAs also have flood defence/ land drainage byelaws which require persons to obtain consent for certain activities within a specified distance of a Main River or Ordinary Watercourse (typically 8 or 9 m, but can be greater). These byelaws very between Environment Agency regions and IDBs/ LLFAs, but include activities such as the planting of trees, erection of fences and alteration of flow, which may be considered as part of plant management techniques.

Appendix B Impacts of aquatic and riparian vegetation on flow conveyance

B.1 Introduction

Conveyance (K) defines the discharge or flow carrying capacity of a watercourse. Conveyance is influenced by the hydraulic roughness of a watercourse and vegetation causing deposition in the channel that will have an impact on its carrying capacity and the relationship between flow and level at a site. The presence of channel and bankside vegetation will influence the hydraulic roughness of a watercourse and any active intervention to modify this may change the conveyance.

Vegetation removal will typically reduce hydraulic roughness, resulting in a more efficient channel, higher water velocity and a reduction in water level for a given flow. Compared with the vegetated condition, this could lead to an increase in the peak flow downstream as the flow capacity of the channel is increased. An understanding of the effects of vegetation removal and the impact this may have on flow could be important if there are critical receptors in close proximity to the river downstream.

The impact of vegetation management on hydraulic roughness and resultant conveyance and flow can be estimated using the conveyance estimation system (CES). This is one of many methods that could be used, but unlike standard hydraulic modelling software, CES is better able to represent the impacts of channel and bankside vegetation on hydraulic roughness and subsequent conveyance.

This appendix provides a basic introduction to CES and gives guidance on when further assessment of the hydraulic impacts of vegetation management is likely to be required.

B.2 Conveyance estimation system

CES software is the outcome from a research and development project by HR Wallingford funded by the joint Defra and Environment Agency Flood and Coastal Defence research programme (R&D Project W5A-057).

The software enables users to estimate the conveyance or carrying capacity of a watercourse. It represents the effects of vegetation in a different way to standard one-dimensional (1D) hydraulic modelling software packages that define hydraulic roughness (associated with flow processes and energy losses) using Manning's n.

An important component of CES is that the software draws on recent research of river resistance and computes a unit roughness on the basis of vegetation coverage, material and the degree of irregularity. Within the software, the unit roughness defines only the boundary friction with the impacts of lateral shearing and momentum exchange calculated using the conveyance generator. As a result, the unit roughness magnitude is equivalent to a Manning's n that has been removed of the impacts of energy losses due to lateral shear, secondary flows and sinuosity, and is hence based entirely on the local boundary friction.

The four components to CES are:

- The **roughness advisor** is used to assign unit roughness values to roughness zones, defined as zones of consistent roughness characteristics, set within a cross-section. The roughness advisor estimates unit roughness based on the vegetation present, the bed material and the degree of irregularity within each roughness zone to produce a recommended value of unit roughness. In addition to this, upper and lower limit estimates of unit roughness are produced by the software to reflect the uncertainty in roughness estimation and allow sensitivity testing to be undertaken.

- The **conveyance generator** uses the estimated unit roughness values in conjunction with cross-section geometry to calculate a series of rating curves. Cross-sections are discretised laterally into 100 divisions with conveyance calculations undertaken at 25 depths (as default), as illustrated in Figure B.1. This is different to Manning's n, which is applied to whole regions of the cross-section. Use of Manning's n in 1D software packages ignores the lateral shearing and consequent momentum transfer between the vertical divisions or 'slices'.

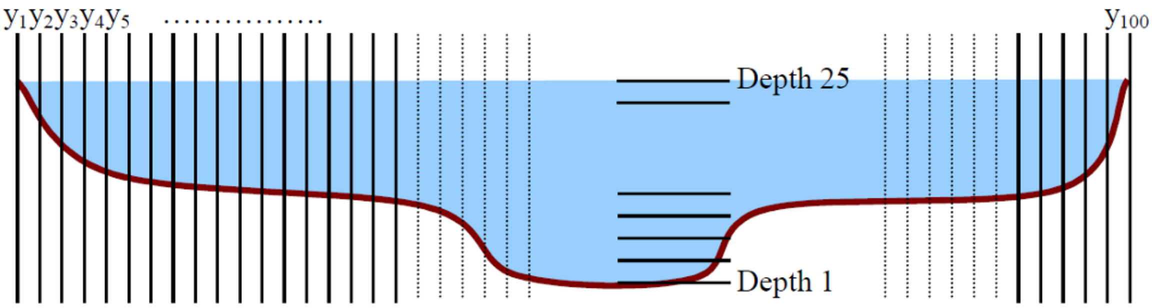

Figure B.1 Cross-section discretisation (HR Wallingford 2004, Figure 2.7)

- The **uncertainty estimator** gives an indication of uncertainty associated with CES outputs using the calculated upper and lower unit roughness values.

- The **backwater calculation module** provides a simple estimation of the backwater profile for non-modellers

The CES is fully documented in the Conveyance Manual (HR Wallingford 2004). The software is freely available and can also be downloaded as a standalone executable from the dedicated CES website (www.river-conveyance.net). The software has also been integrated into ISIS Flow and InfoWorks RS 1D river modelling software packages.

The outputs from CES include site-specific stage-conveyance/ flow curves, depth-averaged velocity information and back calculated Manning's n values.

Typical outputs from application of the conveyance generator within CES software for small (4 m wide) and medium (14 m wide) sized channels are shown in Figure B.2 and Figure B.3 respectively. These demonstrate that channel and bankside vegetation clearance can have a significant impact on the conveyance capacity of a watercourse, particularly in small and densely vegetated channels. In the example, the capacity of the 4 m wide channel is shown to more than double as a result of vegetation clearance.

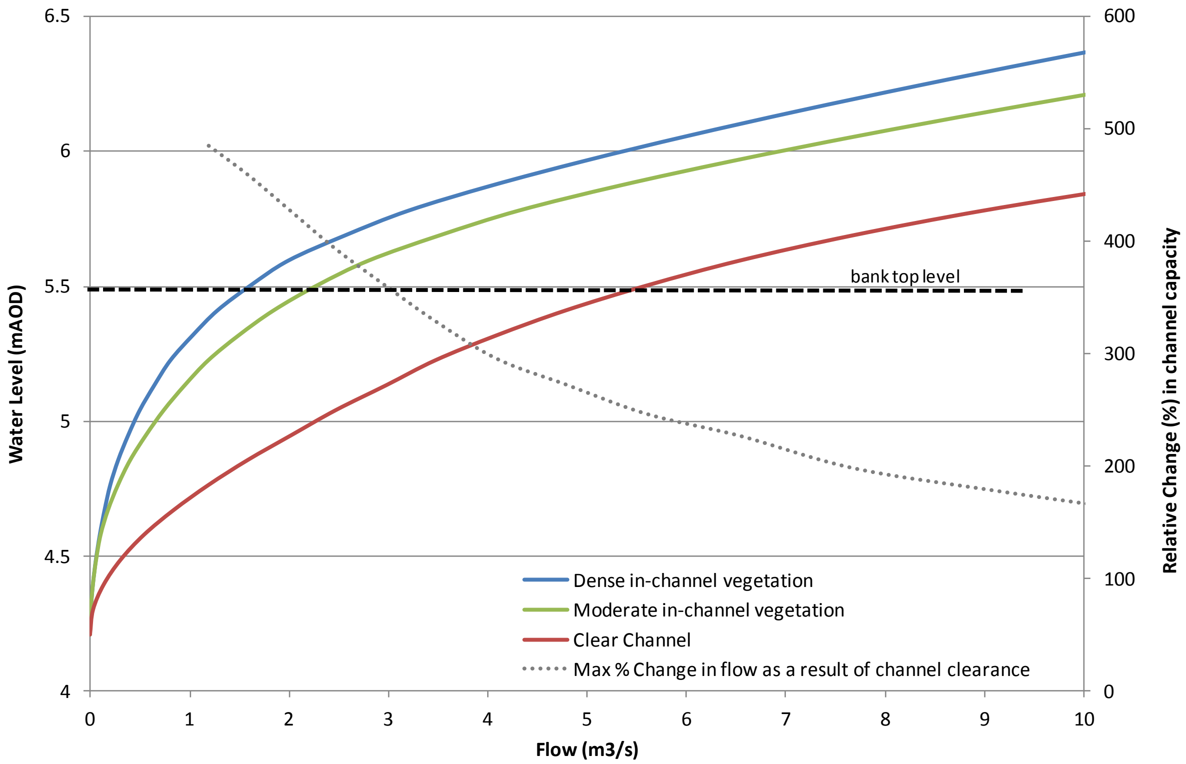

Figure B.2 Rating curves produced for vegetated conditions in a typical 4 m wide channel

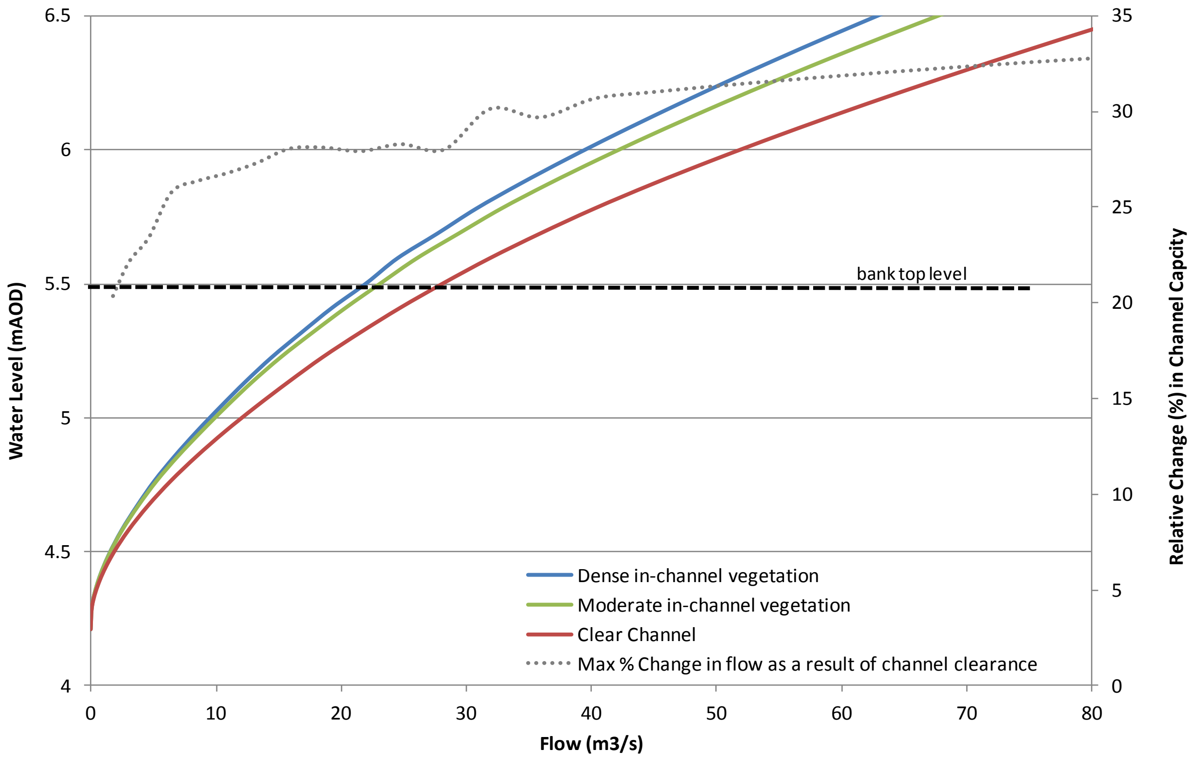

Figure B.3 Rating curves produced for vegetated conditions in a typical 14 m wide channel

B.3 Assessment of the hydraulic impacts of vegetation removal

Watercourse managers need to aware of the impact that channel and bankside vegetation has on hydraulic roughness and flow conveyance and the potential impact of change.

The possible hydraulic impacts of reducing vegetation are:

- a more hydraulically efficient channel with an overall lower hydraulic roughness
- an increase in velocity resulting in a reduction in water level for a given flow
- an increase in the (at-site) channel capacity that may convey more floodwater downstream – the timing of the hydrograph may also be affected as a result of the local increase in velocity and flood peaks may arrive earlier
- increasing likelihood for sediment transport as a result of the removal of vegetation (that helps stabilise the bed and banks) and an increase in velocity

There are circumstances where an increase in flow downstream may increase the frequency and magnitude of flooding. Depending on the nature of the changes and the catchment characteristics, this may warrant further investigation before conducting vegetation management.

When initially assessing the potential impact on flood conveyance, catchment managers should consider whether:

- the watercourse and catchment are likely to be sensitive to a change in flow conveyance
- there are key receptors downstream

Further investigation may be required if there are key receptors downstream that are either in close proximity to the watercourse or are known to be at risk of flooding from the watercourse.

Other influencing factors that should be considered are as follows.

- **Size and nature of the watercourse.** The hydraulic impacts of vegetation are likely to be most critical for small watercourses that could have a significant change in capacity as a result of vegetation management. A notable impact of vegetation management on downstream flood risk receptors is not expected on large watercourses where the channel width exceeds 20 m. This is illustrated in Figures B.2 and B.3 which show that, in the example catchment, the change in bankfull capacity as a result of channel clearance (from dense vegetation) could be as much as 250% in a small 4 m wide channel reducing to less than 30% in a 14 m wide channel.
- **Distance and/ or change in catchment area downstream.** When considering downstream implications, the distance downstream and the change in catchment area should be considered as the impact of upstream change will dilute with distance downstream and increasing catchment area and hence the change in flow may become negligible over large distances. The FEH CD-ROM can be used with OS mapping to estimate the change in catchment area and distance. If access to the FEH CD-ROM is not available, the Main River centreline shown on the Environment Agency’s flood map (https://www.gov.uk/check-if-youre-at-risk-of-flooding) will give an indication of the likely change in catchment area between the vegetation management site and the receptor site on Main Rivers.

- **Existing flood risk within the catchment.** Inspection of the Environment Agency's flood maps will help to identify areas downstream that are at flood risk where the frequency and magnitude of flooding could be increased as a result of upstream changes.

- **Seasonal implications.** The impact of vegetation (and the potential impact of management) during the summer months, between July and September should be considered when it will be most dense. The impact on conveyance and downstream flows is expected to be at its greatest during these months. For smaller and steeper catchments summer storms can prove more critical.

- **Cumulative impacts.** The potential for cumulative impacts to be produced as a result of vegetation management being undertaken on separate but neighbouring drains upstream of key flood risk receptors should be considered.

Depending on the site-specific circumstances, further assessment may be required.

The process is summarised in the flow diagram shown in Figure B.4.

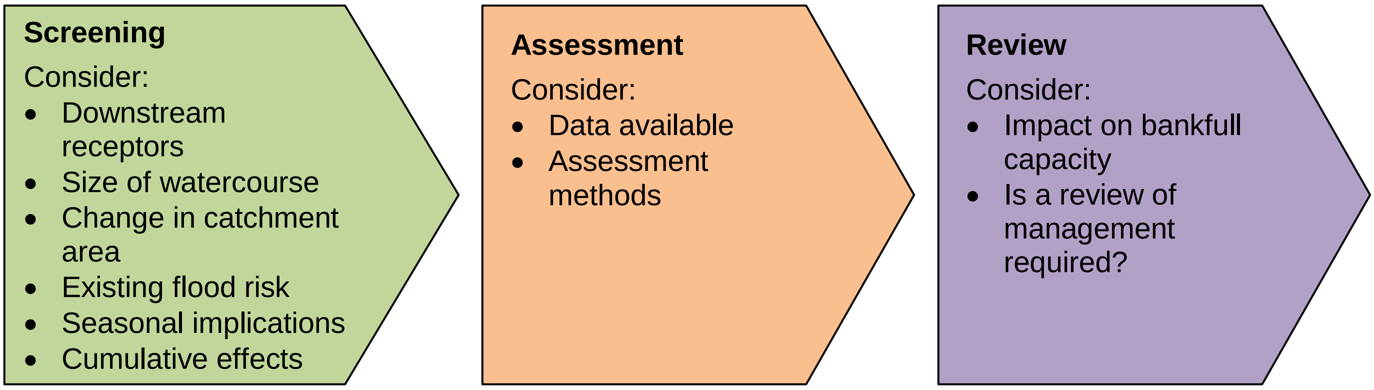

Figure B.4 Assessing the hydraulic impacts of vegetation removal

B.4 Use of CES to quantify the change in flow conveyance

The standalone version of CES can be used to estimate the change in flow conveyance as a result of vegetation removal. In the absence of a hydraulic model this is considered to be a suitable screening process. If a hydraulic model is available, please refer to section B.4.1 for further details.

To use the CES the following information will be required:

- an approximation of the geometry of the cross-section at the proposed management site and downstream in the section adjacent to key receptors – both can be estimated on-site, defined using existing survey data or surveyed as part of the assessment

- watercourse gradient – this can be estimated using survey collected for the assessment if available or can be approximated using a Digital Terrain Model, such as LiDAR data or freely available OS Terrain50 grid by setting the watercourse gradient equal to the estimated gradient of the floodplain

- information to define the vegetation present within the channel, bed and bank material and the degree of irregularity at both sites – this information can be obtained from a site visit

In addition, any gauged flow information within the catchment (for example, at a flow gauging station) can be used to define bankfull capacity within the screening process.

Instructions for the use of CES are given below.

1. Open CES software and select ‘Create New Roughness File’. Add new roughness zones to represent the variable conditions (vegetation, material and irregularity) at the site, specifying the type of zone (bed, bank or floodplain). Once the roughness zone has been created, double-click in the relevant entry to edit vegetation, material and irregularity components. Repeat this until all required roughness zones have been added for all subject sites. Save the .rad file once complete. This process is illustrated in Figure B.5.

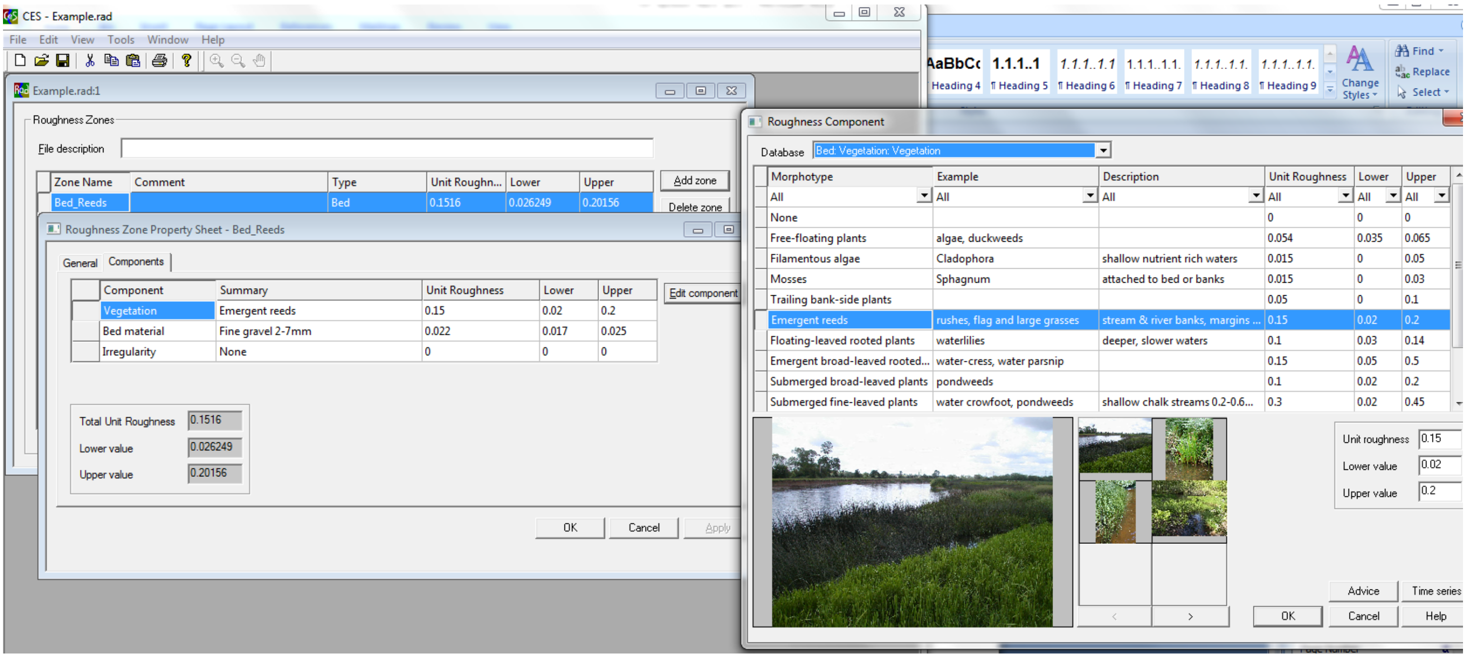

Figure B.5 Setting up the .rad file

2. To create a conveyance file Go to File/ New/ Conveyance Generator. On opening, users will be asked to specify the .rad file created by Step 1. In the Cross Sections tab – click ‘Add Section’ and specify the approximate slope and the sinuosity. Double-click the entry created to specify the cross-section geometry (in the Section Data tab) and set the appropriate roughness zones (that are specified at the chainage at which a particular roughness zone starts). The ‘Outputs’ and ‘Distribution Plots’ tabs allows the output from the calculations to be viewed. Use the ‘Output to file’ option in the ‘Outputs’ tab to export the outputs to an external file of choice. This step is illustrated in Figure B.6.

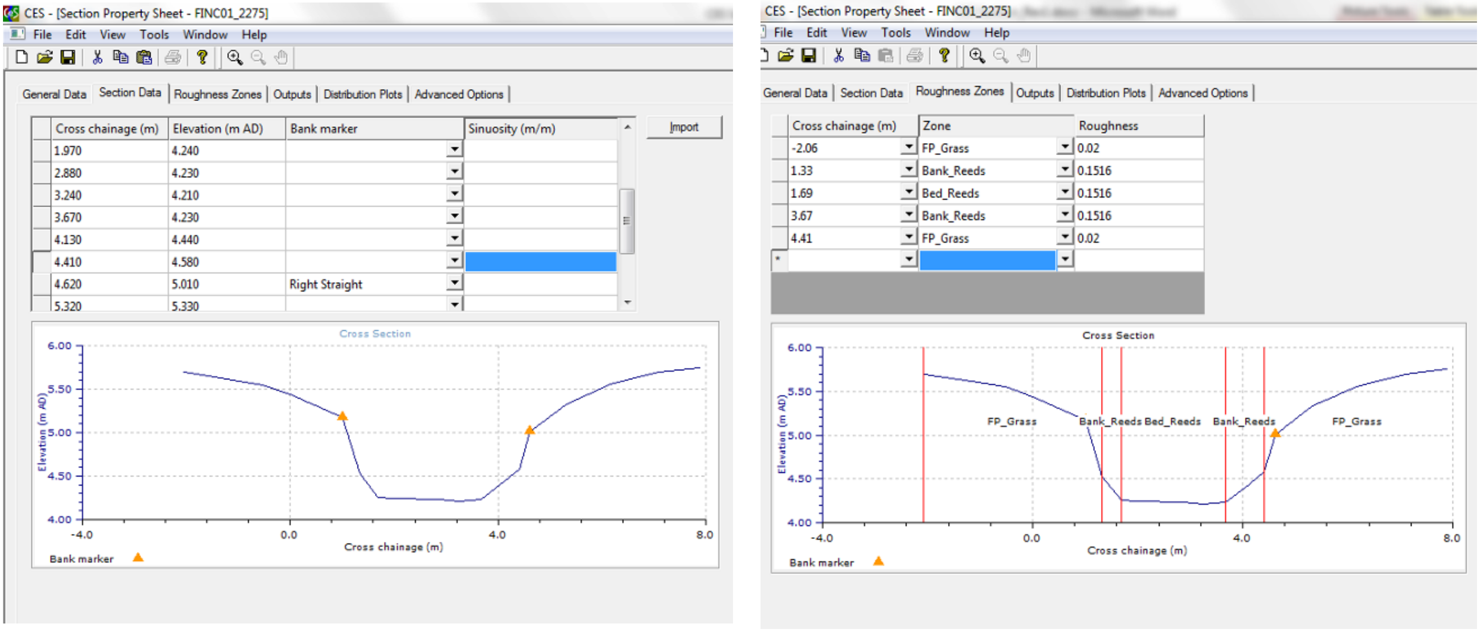

Figure B.6 Inputting data into the conveyance generator

3. Repeat Step 2 for both the pre- and post-vegetation management cases at the vegetation management site and downstream at the receptor site to allow comparison between the predicted outputs. The software will calculate data up to the highest level included on the cross-section and it is particularly relevant to look at the change in flow capacity at bank full level (as above this flow may be attenuated by floodplain storage). An example comparative set of outputs are shown in Figure B.2 and Figure B.3 that illustrates the predicted difference in stage for a given flow for heavily vegetated, moderately vegetated and cleared cases.

The predicted outputs can be used to understand the impact that the upstream change in bankfull capacity might have on water levels downstream. This can be determined using the calculated rating curve to estimate the likely water level increase as a result of the predicted increase in downstream flow. Further more detailed investigation should be made if water level increases are considered to be significant. The significance of water level increases should take into account the nature of the catchment, its gradient and hydrological response. As a guideline, it is recommended that predicted water levels variations that are greater than 0.2 m are investigated further although the suitability of this criterion should be reviewed on a catchment specific basis.

Where there are key receptors downstream identified to be adversely affected managers and/ or operators should consider if the screening assessment completed is of sufficient detail to be able to confidently make decisions about future management or whether a more detailed assessment is required. In extreme cases, the outcome from the screening assessment may prompt a review of the proposed vegetation management.

Worked example

The predicted rating curves for small and medium channels shown in Figure B.2 and Figure B.3 can be used to illustrate the screening process described above, with the data shown in Figure B.2 used to represent the upstream vegetation management site and the data in Figure B.3 to represent the downstream site.

Figure B.2 shows that, at the vegetation management site, the bankfull capacity of the watercourse is increased by 3.5 m^3/s from approximately 1.5 m^3/s in heavily vegetated conditions to 5 m^3/s as a result of vegetation clearance.

At the downstream site, Figure B.3 shows that the channel capacity is significantly larger at approximately 20 m^3/s.

Using the rating curve produced from CES, it is possible to estimate that the additional downstream flow of 3.5 m^3/s would result in a 0.1 m increase in predicted water level (calculated at bankfull level).

Given this and the significant change in the predicted bankfull capacity at the downstream site, further assessment in this case may not be required. However, if the key receptor was only a short distance downstream of the vegetation management site (and Figure B.2 is representative of both sites), further assessment would be recommended given that the increase in flow relative to the channel capacity and water level (of 0.3 m) would be more significant.

B.4.1 Alternative methods of assessing hydraulic impacts

Hydraulic models

If a 1D hydraulic model of the watercourses exists, this can be used as an alternative means of estimating the impact of vegetation removal on flows downstream. In doing so, modellers should be bear in mind that they will not be able to use the unit roughness calculated within CES directly in most standard hydraulic modelling software packages that are based on Manning's n for the reasons outlined in section B.2. The known exceptions to this are within ISIS and InfoWorks RS where CES has been integrated into the software and can be used.

Despite this integration, most 1D river models even within ISIS do not use the CES functionality, although there are tools available within ISIS to convert River Sections to CES Sections. If CES functionality is not possible, it will be necessary to represent the impacts of vegetation and its removal by the allocation of Manning's n values. The back-calculated values of Manning's n estimated by CES could be used to get an indication of the relative change in roughness, to be represented within the model.

Hand calculations

Hand calculations using Manning's equation can be undertaken as a quick and easy way to understand how changes in vegetation management might affect bankfull capacity. Manning's equation, expressed in terms of flow, is given below.

$$Q = \frac{AR^{\frac{2}{3}}Sf^{\frac{1}{2}}}{n}$$

where:

Q = flow (m^3/s)

A = area (m^2)

R = hydraulic radius (m)

Sf = bed slope

n = Manning's 'n'

Summary

The advantages and disadvantages of the available methods are summarised in Table B.1.

The methods outlined in this section seek to estimate the change in conveyance and the potential bankfull capacity of a watercourse that could occur as a result of vegetation management. The methodology does not consider the opposite impact that vegetation management could have on sedimentation and channel blockage that may reduce bankfull capacity. These impacts need to be considered separately.

Table B.1 Advantages and disadvantages of available methods

	CES	Hydraulic model – Manning' n	Hydraulic model – CES	Hand calculations using Manning's equation
Definition of the impact of vegetation on hydraulic resistance	Good – method draws on extensive research to understand impacts of vegetation on channel resistance and hence allows a detailed representation of the effects of vegetation. NB Energy losses due to form change are not considered.	Approximated – typically defined using Manning's n.	Good – as per CES	Approximated – typically defined using Manning's n
Useability	Easy – method is relatively quick and easy to use, reliant on only limited input data (that can be approximated). Software freely available to all.	Difficult – modelling experience required. Access to software may not be freely available.	Difficult as per hydraulic model	Easy –method is quick and easy to use, reliant on only limited input data (that can be approximated). No software required.
Representation of backwater effects and downstream flow attenuation	No – method does not make any allowance for the potential backwater effects or flow attenuation downstream that may affect flow. These impacts could be represented using the Backwater Calculation Module (see Conveyance Manual for	Yes – resulting in more accurate predictions of the consequences downstream	Yes – resulting in more accurate predictions of the consequences downstream	No

	CES	Hydraulic model – Manning' n	Hydraulic model – CES	Hand calculations using Manning's equation
	further details) or using a detailed hydraulic model if thought to be significant.			

Appendix C Linking watercourse type classifications

This appendix provides a summary of the linkages between the most commonly used classifications in the UK and the classification system used in this guide.

The geomorphic watercourse types used in this guide have been assigned to the 10 JNCC classifications and the 18 UKTAG classifications to provide important information regarding species types, linking this to geomorphic processes. It can also be utilised as a predictive tool as part of river restoration.

For example, if river energy is likely to increase as a result of restoration works, changing the river type from an inactive single thread channel to an active channel, the potential changes to species assemblages can be predicted.

Vegetation management techniques can also be critiqued against the likely impact to channel form, and process and consequential impacts to species assemblages.

These key comparisons also allow conclusions to be drawn on what species are common, or not common, to specific watercourse types and management/ restoration can then be focused on ensuring species are appropriate to the river type and naturalised conditions.

A comparison has been made between the geomorphic watercourse type classification used in this guide based on the JNCC and UKTAG types (Table C.1). Although both classifications are broadly similar, further typologies have been used to define channelised low energy channels.

Table C.1 Linkages between JNCC and UKTAG watercourse type classifications

Geomorphic watercourse type	JNCC type	UKTAG type
Step pool channel	CVIII, DIX, DX	2, 3, 10, 11, 13, 16, 18
Bedrock channel	CVIII, DIX, DX	10, 11, 18
Wandering channel	BV, BVI, CVII	16, 1, 2, 10, 11, 12, 13, 15, 16
Active meandering	AIII – IV, BV, BVI, CVII, CVIII, DIX	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17
Pool riffle channel	BV, BVI, CVII, CVIII, DIX	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Plane bed channel	CVII, DIX	1, 2, 4, 6, 7, 13, 14, 15, 16, 17
Inactive single thread channel	AI to AIV	6, 7, 9, 14, 15, 17
Canal/ reinforced drainage channel		
Modified urban watercourse		
Ditch/ small drain		
Artificial drainage channel		

Appendix D Background to decision-making spreadsheet tool

This appendix provides further detail on how the Decision-making Spreadsheet Tool has been developed and how it works. The tool has three elements:

- an assessment of the effectiveness of each technique in managing a species
- an assessment of the potential impact of each technique on different watercourse types
- an appraisal of the technical limitations (for example, channel width, water depth, watercourse length) of each technique

D.1 Effectiveness of technique for a specific species

This aspect of the decision-making spreadsheet tool assesses a variety of potentially problematic species against the possible techniques that could be employed to manage them. Each species is given a score from 0 to 3, based on the effectiveness of each technique to control the particular species. This scoring system is as follows:

0 = Not an option for control

1 = Limited potential for control

2 = Moderate potential for effective control

3 = Most potential for effective control

The assessment of effectiveness is based on a review of literature conducted as part of this project. This information has been judged professionally to come up with an effectiveness score which encompasses three aspects:

- **Feasibility.** It is not feasible to use certain techniques in relation to some species. For example, given the nature of the machinery involved, it is not possible to manage submerged species with an excavator and tractor mounted cutter/ flail and in relation to these species a score of 0 is given for this technique. Similarly, there are no herbicides available for use on submerged species, and for all species within this group (except those which may also have emergent parts at some times such as parrot's-feather), a score of 0 is given. Scores of 0 were also given where control using a specific technique is strongly discouraged. For example, Japanese knotweed should not be controlled by excavator mounted cutter/ flail due to the risk of fragmentation and spread, and this is scored as 0.
- **Longevity of control.** Where a number of techniques can be used successfully in relation to a specific species, the scoring given includes an assessment of how often repeat management is likely to be required. Some techniques result in control for more than one season, whereas others only result in control for one season (or less). For example, branched bur-reed can be managed effectively by physical techniques such as de-weeding with a weed cutting bucket and a weed boat, but as these techniques do not remove the rhizomes, regrowth is often rapid; a score of 2 is therefore given. De-weeding with a solid bucket removes the rhizomes and re-establishment of dense communities takes a longer period of time, reducing the frequency of retreatment required and a score of 3 is given. Similarly, use of herbicides on branched bur-reed can result in reduced growth and no need for further management for up to three years, and again a score of 3 is given.

- **Predictability.** The outcomes of the different management techniques are not always predictable or certain, and this has been factored into the scoring. Some of the techniques involve active management of which the outcome can be relatively certain and controlled (for example, de-weeding with a weed bucket, herbicide application), whereas some of the more uncommon techniques, particularly those within the biological category, are more passive and the outcomes of using them to manage vegetation are less predictable and controllable. As a result these are scored relatively less than those active management techniques. For example, the use of waterfowl or fish as a management technique is difficult to control as they are non-selective and mobile, being able to move away from the problem area; as they may not manage the target vegetation in the desired way these techniques cannot be scored particularly highly (that is, a score of 1). Similarly, fencing to allow vegetation along banksides to grow and shade the watercourse may not result in growth of vegetation tall enough to do this or it may not grow in the desired locations as anticipated; this technique is not scored higher than 1.

It is recognised that some watercourse managers will not have the expertise to identify an aquatic or riparian plant to species level and therefore scores are also given to a number of groups of species (that is, submerged, free-floating, floating-leaved rooted, tall emergent, broad-leaved emergent). These scores are derived from the common score within a group, where possible, not taking into account the scores for non-native invasive species. In instances where a technique can be effective on one species within a group but is not an option for another species in a group, a score of 0 is always given so that an inappropriate technique is not applied. While identification to species level is encouraged, in those instances where this is not possible these species groups can be used.

D.2 Potential impact of technique on different watercourse types

A traffic light system has been used in the spreadsheet tool to highlight the risk of damage. A response index for depositional processes and other processes influencing wider channel stability has been used along with an impact index for the management action on the bed and bank sediment disruption and channel transport processes.

The combined index is a product of the channel sensitivity and management impact on sediment dynamics.

D.3 Technical feasibility of each technique

The third element of the decision-making spreadsheet tool considers the technical limitations of different techniques. This provides a high level screening to the entire list of techniques that are possibly available and screens out those that are unsuitable to a specific type of watercourse based on consideration of the physical parameters of the watercourse.

The decision-making spreadsheet tool requires users to input the following details at the start of the process:

- length of watercourse to be maintained (m)
- channel width (m) (that is, wetted width).
- water depth (m)

From these data, only those techniques that can be used on watercourses with those physical parameters will be returned as options. For example, in relation to the length of watercourse to be maintained, using large machinery and plant such as weed boats or weed cutting buckets is not considered to be feasible over short lengths of watercourse due to the mobilisation costs involved. These techniques will therefore not be returned as an appropriate option where less than 500 m of watercourse requires management. Similarly, a technique such as ultrasound treatment of water requires a power source and would not be a feasible option to maintain significant lengths of watercourse (that is, over 500 m).

With regard to the width of watercourse to be maintained, techniques which require in-channel vehicles such as weed boats, amphibious vehicles and harvesters cannot be used on narrow watercourses. A minimum channel width requirement of 4 m is included as a technical limitation for these techniques.

In relation to water depth, certain machines such as weed boats can only be operated in a certain depth of water. These techniques are screened out where water depths are shallow (<0.4 m). Likewise, a technique such as using broad-leaved native vegetation to shade out other problematic plants can only be used in channel depths where these plants can establish (usually no more than 2.5 m); therefore this technique will be screened out for any watercourses of greater depth than this.

In some instances there are no technical limitations to what length/ width/ depth of watercourse that a certain technique can be applied. A nominal value is given in the spreadsheet so that the technique is automatically screened into further assessment.

D.4 Assessment

The three aspects of the Decision-making Spreadsheet Tool are then combined together to give a score:

$$\text{Score} = (\text{Effectiveness of technique}) \times (1 - \text{Impact of technique on river type}) \times (\text{Technical feasibility})$$

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