Appendix B

Mitigation Measures and Management Strategies Sheets

A COMPANY OF

ROYAL HASKONING

CONTENTS

1 REMOVAL OF BANK REINFORCEMENT / REVETMENT, OR REPLACEMENT WITH SOFT ENGINEERING SOLUTION

The ideal solution to mitigate impacts associated with hard bank protection is simply to remove the defences, and either leave the bank to adjust naturally in response to fluvial and morphological processes, or recreate a natural bank profile (see mitigation measure 6). The removal of protection will allow the future adjustment of the bank profile improving diversity of niche habitats. This measure should only be applied after geomorphological / geotechnical assessments have been undertaken to establish the likely extent of erosion, bank stability issues, and any implications for the future navigability of the channel. In rivers, re-initiation of natural processes of erosion and minor adjustment of the bank profile may promote a more natural sinuosity within straightened rivers. Given the extent of hard bank protection associated with canals, it is unrealistic that this measure could be considered for existing areas of hard bank protection, however, it's implementation should be considered where hard bank protection is scheduled for replacement.

Within larger channels, reed beds can be incorporated with these measures to counter erosion, and therefore, the need for hard bank protection will be reduced. Established fringes of emergent vegetation can dissipate 60-80% of wave energy from boat wash (Bonham, 1980). The rhizomes and roots of reed species act to bind the soil firmly in place, and in so doing, help to prevent erosion and substrate slippage (Caffrey and Beglin, 1996). Their ability to survive heavy boat traffic and river spates can be increased by protecting them with geo-textile or other materials, especially during their establishment phase. There is, however, a limit to the intensity of traffic and / or river flows that even root protected reed can withstand. In canals, where only traffic stress applies, this limit is high (>3000 passages per year in small channels: Eaton *et al.*, 2007). In rivers subject to strong spates, it is the stress conditions in flood periods, rather than boat traffic, that may limit the use of reed protection.

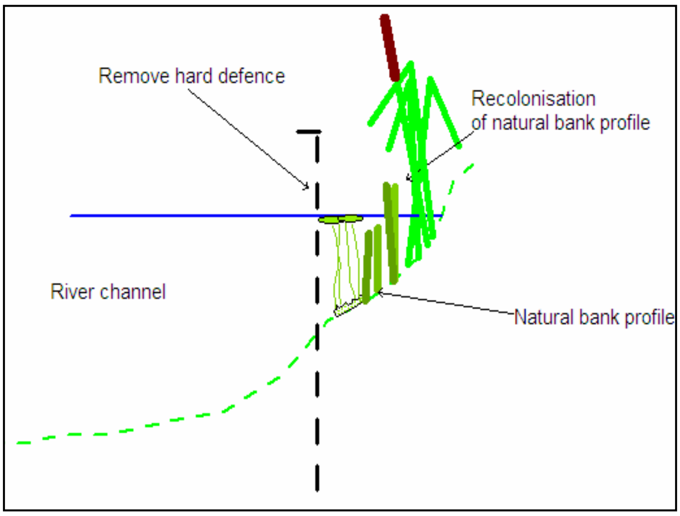

Figure 1.1. Hard defence removed

However, a naturalised bank will not always be able to accommodate some requirements for navigation, such as locks, weirs and mooring points. In general, the removal of hard bank protection will not be acceptable where:

- It would create unacceptable degrees of channel or bank instability; or
- Traffic is too high for vegetated alternatives.

(John Eaton, *pers. comm.*, 2007)

As an alternative, it may be possible to remove hard defences and replace them with ‘soft’ engineering techniques in order to preserve their form and function. The objective of soft engineering is to create a sustainable plant community which has engineering as well as ecological value. Bioengineering relies on the engineering use of vegetation to protect the bank. Biotechnical engineering takes the process a stage further and incorporates engineering structures with the engineering and environmental benefits of vegetation. This approach has greater design certainty, compared to vegetation or bioengineering alone and effectively provides additional assurance, should the vegetative element fail (Environment Agency, undated). Methods for both include:

- Coir rolls to establish vegetation. These are available pre-planted with emergent plant species, which is preferred due to more rapid establishment;
- Willow spiling (on rivers only as live willow can grow and damage canal banks);
- Hazel faggots;
- Willow mattress revetment (on rivers only – see above);
- Plant roll revetment;
- Timber revetment (hurdle and coir roll);
- Brushwood marginal shelves;
- Pocket fabric revetment / reinforced vegetative bank protection;
- Open cell revetment (e.g. geotextiles in lattice providing gaps for planting);
- In-stream protection (floating boom, geobags, stake and batten, log barriers);
- Grassed composites (reinforce grass bank with geotextile);
- Toe geotextiles;
- Toe rolls;
- Toe protection (log toe, timber piling); and
- Rock rolls.

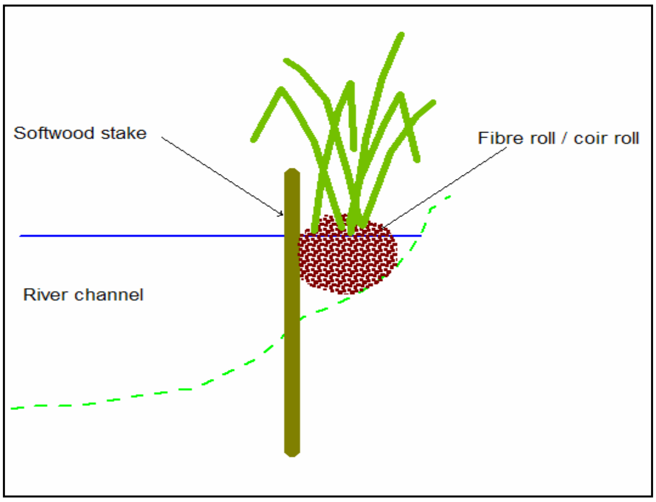

Figure 1.2. Soft engineering (coir roll behind softwood stakes)

Many of these techniques allow the retention of the natural form and function of the protected bank, and therefore have less marked hydromorphological consequences than hard engineering solutions. The structural component of these techniques (e.g. coir rolls or hazel faggots) is organic but non-living, and is designed to provide sufficient protection for emergent plant species to become established. Once protective communities have become established, the structures will biodegrade.

Figure 1.3. Installation of coir rolls

Figure 1.4. Bank reinforced with reed (pocket fabric revetment)

1.1 Hydromorphological / ecological effectiveness

Bank naturalisation is likely to have a number of significant impacts on a watercourse. The percentage of bankside structures in a system has been shown to have an inverse correlation to fish species diversity and abundance (Wolter, 2001). This study went further to suggest that the restoration of just 20% of banks within a fully artificial stretch should result in a substantial improvement in fish diversity.

The removal of hard bank protection in navigable rivers re-establishes continuity and connectivity between the riparian habitat, marginal vegetation and aquatic habitat, increases sediment supply and transfer, and serves to support key WFD indicator groups. However, an increase in sediment supply in canals is not considered to be desirable, since it leads to an increased requirement for dredging.

The reintroduction of macrophytes (marginal vegetation) will create as essential habitat for invertebrate groups and fish spawning, and also create nursery areas for fish fry (Hodgson and Eaton, 2000). The introduction of reed beds has been shown to dissipate wave-wash energy (Bonham, 1980; Murphy *et al* 1980; Pearce and Eaton, 1983; Lewis and Williams, 1984) and can provide important spawning substrate and nursery areas for fish (Caffrey, 1993).

Careful bank re-profiling is usually required prior to the installation of reed beds, especially if geotextile is to be laid effectively (Eaton *et al*., 2007), and the feasibility and cost of this should be included in the assessment of this mitigation option.

Soft defences can help to restore connectivity with the riparian zone and allow limited sediment supply from protected banks. They can therefore deliver considerable improvements to hydromorphological quality in navigable rivers, when compared with hard defences. It should be noted that an increase in sediment supply is not an acceptable option in a canal.

Established fringes of emergent vegetation can dissipate 60-80% of wave energy from boat wash (Brookes and Hanbury, 1990), and provides highly effective protection for banks against erosion, as well as nesting habitat for water birds, foraging habitat for other faunal species and a refuge and food source for macro-invertebrates.

Macrophyte beds can be incorporated as measures to reduce erosion and therefore the need for hard bank protection. The rhizomes and roots of reed species act to bind the soil firmly in place, and in so doing, help to prevent erosion and substrate slippage (Caffrey and Beglin, 1996). Reedbeds can provide important spawning substrate and nursery areas for fish (Caffrey, 1993). Geotextile and reed systems have been shown to survive for over 20 years and to support reasonably diverse plant communities, even at relatively high traffic densities, provided the textile is buried away from the light (Eaton *et al.*, 2007).

Care should be taken when considering willow and hazel regeneration, as this can encourage undesirable scrub marginal vegetation. This is particularly true for canals, where the establishment of riparian tress should be avoided in order to prevent damage to banks. In addition, there is limited ecological data demonstrating the quality of the plant community achieved long-term, nor the life expectancy of these wood structures (Eaton *et al.*, 2007; see also Hodgson and Eaton, 2000).

Table 1.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures		✓	✓
Hydromorphological elements addressed		• River continuity	• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	**?**	

2 PRESERVE AND, WHERE POSSIBLE, ENHANCE THE ECOLOGICAL VALUE OF MARGINAL AQUATIC HABITAT, BANKS AND RIPARIAN ZONE

In many instances, the navigable function of the waterway may necessitate a requirement for hard bank protection. For example, where:

- Available space (for soft bank protection) is limited;
- Erosion rates are high (in situations where high flow velocities or boat wash cannot be controlled through boat management);
- Buildings, structures (including moorings and wharfage) or the towpath require protection; and
- Leakage is a concern in canals.

Much of the length of artificial canals has always had a waterway wall of some description, either as part of the original design, or fitted very soon after initial construction when erosion from boat wash became recognised as a problem. These structures were normally made of masonry, but over the years they have deteriorated and been replaced by more modern materials such as steel piling, which have a longer life span and cost less to install.

However, opportunities to incorporate ‘environmental’ measures remain. Effectively, these measures accept that a ‘hard’ engineering solution is required but, where possible, opportunities can be explored that maintain a connection between the waterway and the adjacent riparian habitat.

Hard defences can be lowered or realigned to allow an aquatic connection with riparian vegetation. For example:

- Cut down piling (only considered when installing as new piling); and
- Piling into mid-bank, where engineering constraints (e.g. leak sealing) and hydrological pressure allows this to be installed.

Niche habitat can be created within, and adjacent to, the hard defence, for example:

- Double row piling (planting between the two sets of piles);
- Incorporate planting within hard defence;
- Incorporate niche habitat, for example, incorporate rock (held in place between piles gaps) to encourage invertebrate species;
- Otter ramps;
- Creation of shallow margins in front of hard defence; and
- Cover piles with dredgings.

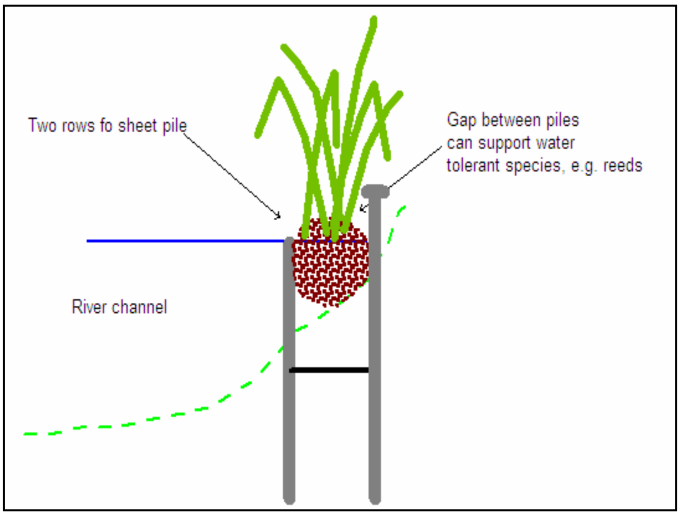

Figure 2.1. Creation of niche habitat (double row piling).

Hard engineering solutions can also be incorporated that may accommodate some limited niche habitat, and therefore retain an element of connectivity with riparian habitat in the long-term, for example:

- Rock revetment;
- Stone gabions; and
- Stone rip rap.

Many of these options may only be applicable when replacing the existing asset, i.e. when the hard bank protection is scheduled to be removed. However, options that do not require structural changes to the existing bank protection, such as the creation of shallow margins in front of the bank protection and the creation of niche habitat, could be practicable in some situations**.**

In some cases, it may not be possible to directly enhance habitat quality. In such cases, opportunities can be sought to compensate for losses of habitat associated with channel modification. These include the direct creation of new habitats in place of those that have been lost, and measures to manage the water level in adjacent wetland habitats. Examples include:

- Create new habitats in the modified channel;
- Re-connect wetland areas; and
- Manage water levels to maintain wetlands – trickle feed / offline pond creation.

The creation and maintenance of compensation habitats can have hydromorphological benefits in addition to ecological benefits, for example, by increasing river continuity and connectivity. A detailed analysis of design criteria for compensation habitats is provided by the Wildfowl and Wetlands Trust (2003).

It should be noted that hard bank protection also represents a habitat type that in some cases will support specialised flora and fauna, for example, freshwater sponges are a noted feature of some canals and dock basins. Any potential or actual impacts should be considered alongside the existing ecological value at that site.

2.1 Hydromorphological / ecological effectiveness

Options to mitigate the existing hard defence can help establish continuity between the aquatic and bankside environment (Briggs, 1998). Where the control of leakage is required, a possible solution may be to drive in sheet piling into the top of bank set back from the bank face leaving undisturbed emergent plants growing on the water side of the piling (Nature Conservancy Council, 1986). This will maintain a limited fringe of marginal habitat, with potential benefits as spawning habitat, supporting invertebrates, etc. However, this will be much less effective than replacing the hard defence with either a naturalised bank, or using soft bank protection (as these options will also restore continuity with the terrestrial environment). The Environment Agency provides manuals and other publications on a range of bank protection techniques, and several trial systems are briefly described in Eaton *et al.* (2007).

Other vertical wall protection, such as timber systems, can maintain hydraulic continuity with the bank and allow marginal vegetation to re-establish. However, where the freeboard is high, continuity will still be lost. Freeboard is provided to prevent overtopping due to surcharge or wave action. In many instances bank protection may be serving as part of a flood defence asset. Therefore, consideration will need to be given as to whether overtopping of water would create a health and safety risk. Overtopping on canals is a serious issue, since they are artificial and often situated above the surrounding land. Overtopping can rapidly erode a canal bank, causing a major breach. This could lead to potentially serious flooding.

In general, the lower the freeboard, the better the situation will be for biodiversity (Briggs, 1998). This is because periodic inundation and nutrient transfer is important for riparian zones. The habitat needs of a healthy riparian zone include:

- Protection from vegetation clearing, as bank slumping may occur and cause altered composition of aquatic plants; and
- Natural river flows and floods, as modifying natural water and sediment regimes may cause the banks downstream to be eroded as the channel readjusts to the change in flow regime. Changes to inundation frequency may also kill riparian plants through excessive drying.

Measures to mitigate the hydromorphological consequences of hard defences may deliver some improvements to hydromorphological quality. However, their effectiveness may be significantly constrained by the remaining presence of the hard engineering structures.

Care should be taken that measures are not employed solely for a slight cosmetic gain. For example, double piling will accommodate vegetation between the two sets of piles, but will not re-establish the link between the terrestrial and aquatic habitats without connecting the terrestrial and aquatic habitats, e.g. incorporating holes in the piles connecting the two habitats. However, consideration must be given to potential siltation issues once a sediment supply is established (i.e. the gap between the two piles may quickly silt up; Boedeltje *et al.*, 2001).

The creation of compensation aquatic habitats can help to improve morphological diversity within a water body, thereby helping to deliver hydromorphological improvements. Issues relating to the quality, quantity and location of potential compensatory habitat will need to be identified and resolved for each individual site. In some instances compensation habitat may be created within the original channel; however, in other instances the creation of new wetlands may be preferred.

Case Study - Off-line Reserves on the Montgomery Canal (compensation habitat)
Offline nature reserves have been established along the Montgomery Canal to achieve full compensation for the aquatic plants that will be affected by increased boat traffic. Recent survey work demonstrates that where fully managed, these reserves have a flora that is representative of the adjacent length of the canal. This therefore enhances the habitat, as the populations remaining in-channel will be net gains (Briggs, 1989; Newbold, 2003; Montgomery Canal Partnership, 2005).

Table 2.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Width and depth variation • Structure and condition of riparian zone

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	?	✓	?	

3 PRESERVE AND, WHERE POSSIBLE, RESTORE HISTORIC AQUATIC HABITATS

Where river straightening, widening or dredging is unavoidable, the creation of backwater features on old meanders may be possible as mitigation. Secondary channel and backwater construction are considered to be important measures for riverine habitat restoration. This approach promotes colonisation of flora and fauna, and increased species richness following habitat development (Bij De Vaate, *et al*., 2007).

Measures to restore / reconnect historic aquatic habitats include

- Trickle feed;
    - Provide a water supply to an adjacent wetland area, for example.
- Offline pond creation; and
- Restore flows to secondary channels, historic flood pathways and isolated backwaters.

There are a wide range of types of backwaters but generally they are low lying areas on floodplains, usually containing water that may or may not be directly hydrologically connected to the main river channel. These features frequently form in abandoned river channels and oxbows. They provide a range of different habitats, including side channels and temporary floodplain pools.

3.1 Hydromorphological / ecological effectiveness

The reinstatement or reconnection of aquatic habitats such as backwaters and adjacent wetlands has been shown to lead to increased emergent vegetation and associated faunal communities, i.e. invertebrates and fish. The predominance of emergent vegetation in navigation backwaters appears to be a consequence of the production of shallow water habitats by sedimentation (Peck and Smart, 1986; Bhowmik and Adams, 1989). In canals, the resultant habitat of very soft, de-oxygenated silt supporting only a low diversity reed flora (often a monoculture), is often of little mitigation value. Willby and Eaton (1996) analyse the conditions required to achieve higher quality ecosystems in restored backwaters.

The restoration or reconnection of natural aquatic habitats can help to improve morphological diversity and increase continuity and connectivity within the system, thereby helping to deliver hydromorphological improvements. This is only really applicable to navigable river systems. As canals are new cuts, there are no historic re-connections to natural habitats to be made. However, there may be scope to restore and reconnect old branches, docks and winding holes in some canal systems.

Case Study - Little Paxton Project; Example of successful backwater connection -
The Environment Agency created a new backwater at Paxton Pits Nature Reserve on the River Great Ouse in Cambridgeshire. The new backwater provides fisheries and wildlife benefits including spawning habitat, nursery areas for juvenile fish and refuge from the main river flows in times of flooding. This year’s fish fry were seen using the new backwater minutes after it had been connected (Environment Agency, 2007).

A fisheries survey, when the river was in flood, showed 4,000 juvenile fish across eight species (including pike, bleak, common bream, perch, tench, roach, dace and chub) were taking advantage of the relative safety and refuge provided by the backwater (Environment Agency, 2007).

This project forms part of the wider restoration vision for the Great Ouse Catchment, and although is not addressing a pressure resulting from navigation illustrates the value of backwater habitats.

Case Study - Rehabilitation of the Morava River; Example of lessons learnt
In the 1950s and 60s, the slow and winding course of the Morava river in Europe was canalised and straightened out. During a recent rehabilitation project, selected cut-off meanders were reconnected to the main river channel. Lack of knowledge of the key river / floodplain processes (hydrological regime, flow dynamics, sediment transport) prior to its implementation resulted in a progressive reduction in the success of these restoration measures, as the meanders silted up. This study demonstrates the importance of detailed study and a sustainable design for integration of cut-off meanders into river systems (Holubova *et al.,* 2007).

Table 3.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures	✓	✓	✓
Hydromorphological elements addressed	• Quantity and dynamics of flow	• River continuity	• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	✓	✓

4 CAREFUL PLANNING OF MOORING FACILITIES AND HIRE BASES TO AVOID SENSITIVE SITES

Many existing best practices already seek to avoid sensitive sites, for example; the British Waterways Inland Marina Investment Guide, the section on moorings in the British Waterways Code of Practice for Works Affecting British Waterways, the Broads Authority Mooring Strategy and the Conservators of the River Cam Mooring Policy.

It is accepted that boat users need a mooring point to secure their vessel overnight. Visitor moorings are required whilst cruising, and permanent moorings are required legally as a home base by most navigation authorities. However, the choice of location for mooring facilities should show appreciation for the wider environment and an understanding of potentially sensitive areas (e.g. designated sites and sites considered to support notable habitat / ecology, etc). This decision should, therefore, involve early input from an ecologist.

The hydromorphological consequences of boat mooring should also be considered when the location of mooring facilities is being planned. Care should be taken to avoid areas that are hydromorphologically as well as ecologically sensitive, for example those areas that already exhibit signs of bank erosion problems (both as a result of navigation activities, and erosion attributable to unconnected processes). The siting of mooring sites on areas where erosion is likely to develop should also be avoided, for example on unprotected or unvegetated banks, those composed of easily erodible sediments, and those with a steep profile that may be susceptible to damage and instability. In general offline mooring facilities (i.e. offline marinas) should be favoured over online mooring. Indeed, this is a stated policy of British Waterways (2007).

4.1 Hydromorphological / ecological effectiveness

As much pleasure cruising is over relatively short distances, moorings often localise the densest traffic, so planning their locations away from ecologically sensitive stretches makes it possible to control boat numbers on those stretches without resort to overt restrictions of access to them (Eaton, 1997). A computer modelling procedure is used by British Waterways (G. Millar, BW Watford, *pers. comm.*) to predict traffic spread away from proposed new moorings and this can be used to reduce the ecological and hydromorphological consequences of boat activity in sensitive areas, for example by prohibiting mooring in areas where bank erosion is already a problem or vulnerable habitats exist. It is particularly important to either avoid locating temporary as well as permanent moorings on sensitive lengths or, if they are essential for operational reasons, to design them to minimise the intense disturbances caused by boats starting and manoeuvring (Eaton *et al.*, 2007).

Table 4.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures		✓	✓
Hydromorphological elements addressed		• River continuity	• Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	**?**	✓

5 LIMIT NUMBER OF MOORING PERMITS AVAILABLE

Limiting the number of mooring permits available will ultimately control the number of boats using a waterway, and therefore the extent of boat related mooring impacts. This strategy has been employed along the River Cam, where the Conservators of the River Cam have lobbied Cambridge City Council to limit the number of permits available to 70. This has subsequently been implemented by the Council, in order to reduce the pressures caused by boat traffic on the river system. This approach is also used on the Basingstoke Canal SSSI, together with control of boats coming on to the canal from the River Wey.

To control the pressures caused by boat movement, it is necessary to limit all types of moorings (both offline and online). However, to control the pressures caused by online moorings, it is only necessary to place a limit on this type of moorings; offline moorings can remain unaffected. British Waterways favours offline moorings, and aims to progressively reduce the number of online moorings as offline moorings become available in the locality (British Waterways, 2007).

5.1 Hydromorphological / ecological effectiveness

Limiting the number of mooring permits is considered reasonably effective at reducing boat numbers (Philippa Noon (Conservators of the River Cam) *pers. comm.*, 2007). Illegal mooring is still liable to take place, however, and the success of the scheme is reliant on bailiffs to enforce the rules.

If it is assumed that the extent of illegal mooring is not significantly greater as a result of limiting mooring permits, then the impacts associated with mooring should effectively be reduced relative to the number of permits available. However, there is no documented evidence of this effectiveness, and future monitoring would need to establish the link.

The hydromorphological effectiveness of this measure is dependent on the scale of the reduction in boat traffic that occurs once it has been introduced. If traffic volume is reduced considerably, the hydromorphological pressures caused by boat mooring and movement (e.g. bed and bank erosion) may be significantly reduced. If the impact on boat traffic is small, or in water bodies that are used for boat transit rather than mooring, the pressures may remain largely unaddressed. Furthermore, the success of the measure is also likely to be linked to the type of moorings that are provided in the navigation.

Table 5.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	Hydrological regime	River continuity	Morphological conditions
Effectiveness of measures			?
Hydromorphological elements addressed			• Structure and condition of riparian zone

WFD indicators (biology)	Phytoplankton	Macrophytes	Benthic invertebrates	Fish
Effectiveness of measures	?	✓	?	✓

6 DESIGN MOORINGS FOR ECOLOGICAL BENEFIT

Where moorings are unavoidable, options can be explored that will enhance their ecological benefit. For example, the use of floating pontoon moorings allows the banks to remain natural without the need for a vertical edge, with direct ecological and hydromorphological benefits. Having mooring bays created out of the channel can also provide additional refugia for aquatic species, effectively creating slow moving water out of the main channel. On canals, there is scope for restoring disused branches, docks and winding holes for this purpose (Willby and Eaton, 1996).

In addition, mooring structures can be designed to minimise the hydromorphological impacts of boat mooring. For example, direct contact between the bed and banks can be avoided, and protective vegetation can be encouraged.

Figure 6.1. Out of channel moorings (River Ant)

Figure 6.2. Moorings with reduced loss of riparian habitat (River Avon, Pershore)

6.1 Hydromorphological / ecological effectiveness

Pontoon moorings, for example, can represent noticeable benefits to ecology, acting as refugia for fish and invertebrates. Use of pontoon or floating moorings can also help to deliver hydromorphological benefits. These structures can limit the direct physical impacts of mooring activities, by preventing contact between vessels and the channel banks. Structures designed for ecological benefit (by ensuring that mooring against the bank is not required) are likely to encourage the development of marginal vegetation, providing further hydromorphological benefits by reducing bank erosion. Furthermore, designs which minimise the creation of turbulent flow conditions can help to reduce bed and bank scour.

Table 6.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Substrate conditions • Structure and condition of riparian zone

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	**?**	✓

7 OPERATIONAL AND STRUCTURAL CHANGES TO LOCKS AND WEIRS

This measure is designed for application to navigable rivers and heavily modified water bodies only, and does not apply to canals. The concept of longitudinal continuity does not apply to canals due to their artificial nature.

Locks potentially represent a barrier to fish. Given the low attraction flow of these facilities, which are generally located in calm zones with little throughput of water when not operating, together with the timing of operations, the passage of migratory fish through a lock system is generally fortuitous (Food and Agriculture Organisation (UN), Fisheries Technical paper # 419, 2001).

Locks can however constitute a back-up pass facility for fish, providing their operation is adapted for fish passage. Primarily, sufficient attraction flow must be created downstream in the approach channel to the lock. This can be done for example, by opening the filling sluice to the lock with the downstream gates partially open. Sufficient velocity must be maintained however to encourage fish to proceed upstream into and through the lock facility, although the velocity should not exceed 3.0 m s^{-1}. In cases where there is insufficient flow to maintain navigable water levels, water cannot be run through locks.

Fish passage, for example, has been addressed in a number of sluice complexes on the Maas and Rijn (Holland). By opening the sluices slightly, a water transition is created and the barrier effect of scouring downstream of the structure will be greatly reduced and migratory routes for fish species can be recreated (Bij de Vaate *et al*, 2003).

In summary improved fish passage can be achieved by:

- Operating the lock as a fish pass during migratory periods (i.e. with a specifically designed protocol, e.g. as many times a day at the periods during the day at which migration is greatest);
- Increasing attraction flows;
- Adjusting the position of the lock gates and local flow pattern to attract, retain and assist in the passage of fish through the lock facility. (*e.g.* leaving the lock partially open); and
- Observations of the fish should be made once they are inside the lock facility, and the flows and gate positions adjusted accordingly to help improve passage.

Although these options are suitable for use in heavily modified water bodies, they are unlikely to be practical for application on canal systems, which have insufficient water supply for the operation of fish passes and are unlikely to constitute major routes for fish migration.

The physical presence of an impounding structure such as a weir also prevents the natural[*] movement of sediment. The impounded area typically acts as a sink and traps sediment, especially bedload material such as gravels. In rivers, but not in canals, this reduction in sediment delivery to the downstream reaches can result in an increase in erosion of channel bed and banks. Reducing the accumulation of sediment upstream of locks and weirs can be achieved by either changing their operation, or incorporating

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[*] The concept of natural movement only applies to river navigations.

sluices to allow sediment to be washed downstream of the structure. Trials at Haringvliet (a freshwater lake in Rhine-Meuse river delta), for example, have indicated that opening sluices temporarily has also led to a reduction in accumulated sediments.

The value of this to the morphology of the system however will depend on the ability of the sediment to be mobilized and transported further downstream. In natural rivers where flood flows occur, the mobilization of sediment downstream will contribute to a good morphological condition (e.g. channel pattern, quantity and structure of substrate). However, in systems where flows are not competent to mobilize accumulated sediment, the morphological value will be minimal, other than a local reduction in accumulated sediment upstream of the structure.

In heavily modified water bodies, where localised scouring occurs as a result of the presence of a lock (or weir), mitigation could include sediment replenishment. Sediment replenishment represents an important management strategy for ensuring the ecological and geomorphological integrity of the system is maintained. However, it is only applicable in systems where the sediment will be entrained and transported further downstream by high flow events. In navigation systems where high flow events generally do not occur, such as artificial canal systems, sediment replenishment downstream of structures may not be a practicable option.

7.1 Hydromorphological / ecological effectiveness

The operation of a lock facility for fish passage can often conflict with the normal operation of the lock for navigational requirements, especially where the locks are in regular use. The use of locks as the prime fish pass facility may therefore not be the most efficient method to pass fish upstream, and should only really be considered as an adjunct to a dedicated fish pass facility.

The operation of locks to pass sediment may allow the movement of sediment downstream, and a reduction in the accumulation of sediment upstream of the structure. The value of this to the morphology of the system however, will depend on the ability of the sediment to be mobilized and transported further downstream in the system. In natural rivers where flood flows occur, the mobilization of sediment downstream will contribute to a good morphological condition (e.g. channel pattern, quantity and structure of substrate).

Table 7.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures	✓	✓	✓
Hydromorphological elements addressed	• Quantity and dynamics of flow • Flow velocities	• River continuity	• Channel patterns • Substrate conditions • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**		**?**	✓

8 INSTALL FISH PASSES

This measure is intended for application on navigable rivers only, and is not intended for application on canals, which are not natural fish migration routes.

The aim of a fish pass is to provide conditions to allow ascent of a hydraulic head (e.g. weir or lock) which is otherwise impassable or difficult to the extent that upstream recruitment is compromised.

The objective of re-linking water bodies and habitats has traditionally focused on high profile migratory fisheries species and endangered species such as salmon, trout and eel. Many other species of fish however undertake more or less short term, or small scale migrations from one part of the river to another, either to spawn, colonise, feed or take shelter, or simply to respond to displacement by pollution incidents or flooding. In essence all fish move about the river continuum. The re-linking of aquatic habitats has recently become viewed as important, not only to facilitate the re-colonisation of rivers by important fisheries and endangered species, but more generally to facilitate aquatic species and habitat conservation. See, for example, Jongman & Pungettii (2004) for a general review of the subject. Eaton *et al.* (2007) provide a summary of some of the small amount of direct evidence currently available on the significance of connectivity in water channel ecosystems.

For all types of fish pass there are a number of fundamental issues which need to be considered:

- The appropriate starting point for the ascent should be easily located by the fish (i.e. easily found, effectively attracted).
- The fish should be able to enter the facility without undue effort or stress.
- The fish should be able to ascend and overcome the head difference without expending undue effort or causing undue stress.
- It should be able to leave the pass facility and be deposited in an area appropriate for the continued up stream migration (e.g. there should be no risk of it being immediately being washed downstream over the weir).
- The facility should be effective under all hydraulic conditions which may prevail during the migratory period.
- The fish should be protected from predation at all points along the pass facility.
- Wherever possible the facility should be monitored for effectiveness, and this should be incorporated into the design (e.g. traps or counters).
- The facility should be cost effective.
- It should be sustainable (e.g. use design, materials, and maintenance regime appropriate for the environment).

There are two general categories of fish pass which may be applicable to weirs in heavily modified water bodies; nature-like fish passes, and technical fish passes (although other types of passes exist, such as easements, these are generally only suitable for small scale weirs).

These options are unlikely to be suitable for application on canal systems, which have insufficient water supply and are unlikely to be major fish migration routes.

8.1 Hydromorphological / ecological effectiveness

A large variety of fish passes exist, some of which are specifically designed to target a particular species, e.g. eel (*Anguilla anguilla*), although most can be tailored to allow passage for a range of aquatic species. However, their suitability, effectiveness and efficiency will vary between species (and sizes) of fish. A number of good technical guidance exist which describe the hydraulic and engineering considerations, and the effectiveness of the various fish pass types (see list of references at end of this section). The table nevertheless below provides a brief summary.

Table 8.1. Summary characteristics of some generic fish pass types

Pass Type	Position in channel #	Suitable for which fish species	Benefits to environment other than fish passage
Nature Like Passes			
Rock Ramp- Partial width of weir	In	Most fish species	Habitat creation
Rock Ramp- Full width of weir	In	Most fish species	Habitat creation
By-pass channel	Out	Most fish species, including invertebrates	Habitat creation
Technical (standard) Type Passes			
Eel Ladder	In/Out	Eels	None
Baffled (e.g. Denil)	In	Salmonids, some coarse species with some designs	None
Pool /weir	Out / In	Salmonids, most coarse species with some designs	None

- Position in channel – 'In' refers to a fish pass that can be contained within the channel boundaries. 'Out' refers to a fish pass that is outwith the channel boundaries and requires extra land/space.

Table 8.2. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures		✓	
Hydromorphological elements addressed		- River continuity	

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**			✓

9 AWARENESS RAISING / INFORMATION BOARDS (INVASIVE SPECIES)

Rivers and canals are subject to invasion by a range of non-native species, following a trend that has been apparent for at least 150 years (English Nature, 2003). At the present time, the main nuisance aquatic plants are Australian swampweed (*Crassula helmsii*) and floating water-pennywort (*Hydrocotyle ranunculoides*), although others may be starting to spread, e.g. water primrose (*Ludwigia peploides/grandiflora*).

Information and education is provided by many organisations involved in the control of invasive non-native plants (such as the Environment Agency, Defra, and Centre for Ecology and Hydrology Aquatic Plant Management Group). Information is provided via:

- Newsletters;
- Brochures and posters;
- Websites;
- Workshops and training courses;
- Publications (books, reports, journal articles, conference proceedings); and
- Toolkits and best practice information.

Key resources include:

- DEFRA (Department for Environment, Food and Rural Affairs) code of practice on the problem of invasive non-native plants (http://www.defra.gov.uk/wildlife-countryside/non-native/pdf/non-nativecop.pdf).

- The Environment Agency guidance document for the control of invasive weeds in or near fresh water (http://www.environment-agency.gov.uk/commondata/105385/booklet_895604.pdf).

- Information sheets on the control of aquatic and riparian plants (http://www.ceh.ac.uk/sections/wq/CAPMInformationsheets.htm).

- The Centre for Aquatic Plant Management (CAPM) at the Centre for Ecology and Hydrology, Wallingford, provides research-based advice and information on aquatic and riparian weed control for UK regulatory authorities, flood defence organisations, nature conservation organisations and some navigation authorities, including British Waterways and the Association of Drainage Authorities; http://www.ceh.ac.uk/sections/wq/CAPM1.htm

- The Green Blue provides a usefully simple and compact How To Guide for the public (www.thegreenblue.org.uk), which includes a section on prevention of the spread of alien species.

- The Royal Horticultural Society Website; http://www.rhs.org.uk/advice/profiles0706/invasivenonnative.asp

- Plantlife Website; http://www.plantlife.org.uk/uk/plantlife-campaigning-change-invasive-plants.html

9.1 Hydromorphological / ecological effectiveness

No information could be sourced to assess the effectiveness of such awareness raising campaigns. This measure may have limited effectiveness unless backed up by other measures, such as penalties for non-compliance, etc. However, awareness raising is an important element in achieving strategic control of invasive species. Indeed, it is unlikely that strategic control of these species can be achieved without increasing awareness levels.

Table 9.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			- Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	**?**	**?**	**?**

10 AWARENESS RAISING / INFORMATION BOARDS (SOURCES OF FINE SEDIMENT)

Increased recreational boat use and associated volumes of traffic increases the potential for boat related stress (e.g. boat wash, propeller action, and currents flowing around and under the hull) upon the water body.

Awareness raising campaigns can help to limit these impacts, for example:

- Identifying a need for wharves and marinas to incorporate French drains where runoff is expected;
- Encouraging slipway users to ensure that vehicles entering a water body (i.e. boats on trailers) are not carrying excessive levels of sediment (mud etc); and
- Providing information about sensitive habitats and the need to respect speed limits. The “Boaters Handbook” produced by British Waterways and the Environment Agency tells boat users to respect speed limits, avoid boat wash, and avoid disturbance of wildlife on the offside bank.

Information can be provided via:

- Newsletters;
- Brochures, leaflets and posters (including the British Waterways “Waterways Code” leaflet);
- Websites;
- Workshops and training courses;
- Publications (books, reports, journal articles, conference proceedings, including the Boaters Handbook); and
- Toolkits and best practice information.

In addition to information published by navigation authorities, The Green Blue provides a usefully simple and compact *How To Guide* for the public (www.thegreenblue.org.uk), which includes a section on boat movement.

Finally, increased bankside activities related to the presence of marinas and wharves, and other navigation structures, may cause increased movement between the bankside and aquatic environment, and therefore potential increases in sediment entering the water body. However, this is unlikely to be greater than in any other sector (e.g. agriculture, industry, highways and the water industry).

10.1 Hydromorphological / ecological effectiveness

No information could be sourced to assess the effectiveness of such awareness raising campaigns. This measure is likely to have limited effectiveness unless backed up by other measures, such as penalties for non-compliance, etc.

Table 10.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			**?**
Hydromorphological elements addressed			- Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**			

11 RETAIN MARGINAL AQUATIC HABITATS

Opportunities can be sought to retain marginal aquatic habitats while undertaking channel modification works. These include:

- Work from banks and limit in-channel disturbance;
- Limit work to short sections of the channel at any one time; and
- Limit work to one bank at any one time.

Damage to marginal aquatic habitats can be minimised by limiting in-channel activities; for example, bank reprofiling works can be undertaken from the floodplain, with limited disturbance to marginal habitats.

Marginal aquatic habitats can also be retained by limiting works to short sections of banks at any one time. In this way, any unavoidable damage to aquatic and marginal habitats can be localised, and communities can be allowed to regenerate. Furthermore, channel modification works can be confined to a single bank at any one time. These measures may be particularly useful in cases where in-channel modifications are unavoidable, for example during the deepening of a channel. Where works are required for large stretches of waterway, it may be possible to undertake modifications on non-adjacent reaches concurrently.

11.1 Hydromorphological / ecological effectiveness

Physical modifications to a waterway are likely to have considerable impacts on the hydromorphology of the system, and the ecology it supports. However, the retention of marginal vegetation can go some way to mitigating the impacts of these essential works.

The retention of marginal aquatic habitats is most successful when a range of habitat types are retained, for example plants of different sizes and species. This prevents a loss of species diversity, and allows areas where damage to marginal habitats is unavoidable to become rapidly re-vegetated. Whilst recolonisation can be very rapid where some intact reed plants survive (e.g. Eaton *et al*., 1981; Murphy & Eaton 1981), if all plants have been removed the process is much slower, as reliance is placed on the erratic process of establishment of new individuals either from seed or from drift vegetative fragments. This emphasises the importance of leaving sufficient plants to re-start growth after the completion of engineering operations.

The retention of marginal habitats will also help to deliver a range of hydromorphological improvements, for example, by maintaining the diversity of the river margins and protecting the banks from erosion.

Table 11.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures		✓	✓
Hydromorphological elements addressed	• Quantity and dynamics of flow • Flow velocities	• River continuity	• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	✓	✓

12 INCREASE IN-CHANNEL MORPHOLOGICAL DIVERSITY

Opportunities can be sought to create in-channel features that enhance wildlife and morphology. These include:

- Bank reprofiling;
- Widen waterway corridor to incorporate changes in channel habitat – e.g. to allow bank re-profiling in reaches that are otherwise too narrow (suitable for use in canals[†]);
- Use of in-channel flow deflectors to create backwater areas and encourage localised accretion (only applicable to rivers); and
- Bed raising (sediment replenishment), where sediment starvation is an issue, or the channel is overdeep (other mechanisms for creating depth diversity such as reprofiling should also be considered) (only applicable to rivers).

The edges of a channel can be altered to improve morphological diversity, for example by bank reprofiling, the creation of shallow margins and backwaters and the removal of unnecessary bank protection (see mitigation measure 1). Flow deflectors help to encourage sediment accretion, which can in turn support marginal vegetation.

Eaton *et al*. (2007) review a range of in-channel protective structures that have been used to maintain aquatic plant populations in navigated canals.

In larger navigated rivers, use of suitably unobtrusive soft engineering or equivalent techniques can lead to the creation of a diverse, meandering low-flow channel within a larger channel (Nunnally and Shields, 1985). Alongside the hydromorphological benefits, these measures are also likely to increase habitat diversity.

12.1 Hydromorphological / ecological effectiveness

An increase in in-channel diversity, for example through the creation of a multi stage low-flow channel (limited to navigable river systems), considerably increases the hydromorphological quality of a water body. Furthermore, an increase in morphological diversity is frequently accompanied by the formation of new habitats, and an increase in biological quality. A key issue in the provision of protected areas is their connectivity with other such areas and with the main, unprotected, channel. There is a trade-off between degree of protection and degree of connectivity, with consequent implications for the long-term maintenance of populations and genetic exchange between them. A short discussion of this issue is given by Eaton, Godfrey & Willby (2007).

[†] This technique has been employed by British Waterways, who have created shallow marginal shelves on the Union Canal in Wester Hailes and on the Kennet and Avon Canal in the Bath valley

Case Study- River Avon (Hampshire); Narrowing an over- widened channel
Groynes were placed facing upstream, typically at 60° to the channel. These increased the diversity of the channel, providing variations in flow characteristics. Sediment being transported downstream would accumulate both up and downstream of the groyne, effectively creating a 'natural' narrowing of the channel. Results from this work indicated that the groynes in combination with fencing (to limit access to livestock) led to increases in marginal vegetation and submerged macrophyte diversity (River Restoration Centre, undated).

Case Study - River Skerne (County Durham); Incorporating aquatic ledges
The River Skerne had been straightened and widened for floodwater conveyance, leaving a trapezoidal channel with little diversity and little ecological interest. Ledges were installed using timber posts placed just below the water level, back-filled with riverbed substrate and coir rolls/matting. The ledges were successfully supporting emergent vegetation the following year (River Restoration Centre, undated).

Case Study – Kennet and Avon Canal (Bath valley); Creating marginal shelves
A section of the Kennet and Avon Canal in the bath valley had to be relined in the 1990s when the canal was restored, because of leaks and structural instability of the embankment. The towpath (embankment) side had to have a hard edge for structural reasons and to provide sufficient towpath width for cycling and other leisure uses. Prior to restoration, the embankment was comprised of an earth bank and a heavily eroded masonry wall, and there was, therefore, going to be some loss of riparian habitat. The opportunity was taken to mitigate this by incorporating a shallow marginal shelf which was planted with vegetation and retained when the canal was dredged prior to relining. It has proved successful in enabling recreational use of the waterway while developing a good marginal fringe of emergent vegetation.

Table 12.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			- Channel patterns - Width and depth variation - Substrate conditions - Structure and condition of riparian zone - Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	?	✓	✓	✓

13 SEDIMENT MANAGEMENT STRATEGIES (DEVELOP AND REVISE)

Soft silt is deleterious to aquatic plant growth in navigations, because it is:

- a source of turbidity (leading to reduced photosynthesis) when stirred up by passing craft; and
- a weak anchorage medium for root systems. As a result plants are easily uprooted by the flow stresses arising from boat movement.

A firmer canal bed allows such plants to persist within the waterbody. Therefore the aim is to minimise accumulation of shoals of soft silt in places where aquatic vegetation may grow (Eaton *et al.*, 2007). In canals of high conservation status (*not* the majority), there is scope for assisting bed stability by the use of geotextile and/or thin layers of stones, with silt lodging in interstices (Eaton *et al.*, 2007).

It is often necessary to manage the accumulation of soft sediments through use of dredging. Where in-channel dredging forms part of the management and operation of the navigation it is important that an appropriate dredging strategy informs the decision making process. Such a strategy is expected to consider the following elements:

- Selective dredging;
- Dredging technique;
- Minimise disturbance to riparian / marginal habitats;
- Timing of operation;
- Location of dredged material;
- Source control[‡] within the catchment; and
- Management of temporary water quality impacts.

Selective dredging

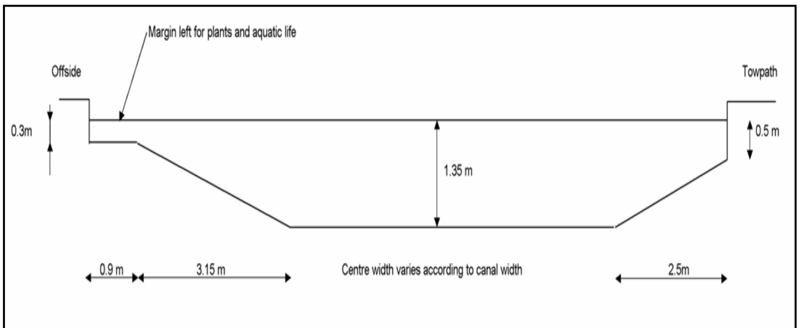
Selective dredging should be undertaken to protect banks, macrophyte beds and important aquatic habitats, as well as reducing the potential for unnecessary or over dredging.

Full channel width dredging should not be undertaken unless essential; instead partial channel width dredging should be performed. Dredging of the full width of channel, especially near the base of the bank can exacerbate bank side collapse and erosion, and result in the loss of marginal habitats and input of fine sediment into the system.

Dredging should also not be undertaken in ‘sensitive’ areas such as near macrophyte beds, spawning grounds, etc., unless it is necessary for navigation or other legitimate reasons, in which case, as much of the habitat should be left as undisturbed as possible to allow regeneration to take place. The location and extent of dredging activities can be ‘managed’ by performing maintenance dredging at appropriate times (i.e. not allowing sediment to build up to the extent that channel wide sediment requires to be removed, or extended lengths of channel dredged). In this way disturbance to macrophytes should be kept to minimum.

[‡] Responsibility for source control within the wider catchment will be outside the control of the navigation authority. It will be the role of the River Basin Management Plan to identify the sectors involved.

In areas where it is necessary to dredge in close proximity to important macrophyte beds, procedures should be in place to minimise the impact to the beds, for example employing selective dredging techniques and programmes to re-use vegetation that has been removed. This can be illustrated by British Waterway's standard dredging profile for a canal which allows a shallow margin (0.9m wide and 0.3m deep) to be retained in the offside as an ecological measure



Where reed fringes exist this profile will be modified to permit the retention of the fringe as required

At lock approaches, bridge approaches and mooring site the dredged depth at the edge will be increased to 0.9 m.

Figure 13.1. British Waterways standard dredging profile

Dredging technique
Inappropriate dredging methods can lead to inefficient dredging, excess spillage (*e.g.* Figure 13.2), re-suspension of sediment, and significant disturbance to aquatic and riparian habitats.

Figure 13.2. Excessive spillage

There are many factors which may influence the selection of a dredging method, including the dimensions of the waterway, access, disposal options, presence of contaminants, cost, and degree environmental impact. CIRIA (1997) provides a series of flowcharts that direct the reader to the most appropriate method, nevertheless Table 13.1 below provides some guidance on the methods, including the main environmental concerns and benefits.

Table 13.1. Summary of dredging methods and main environmental concerns. (See 'Inland dredging – guidance on good practice', CIRIA, 1997 for more detail).

Type	**Land based or Floating**	**Suitable for what type of operation**	**Environmental concerns #**
Dragline	Land	Rivers with good open bank access, and where dredgings can be spread over adjacent land.	Requires more space to operate than other bank dredges, therefore greater bank disturbance. Difficult to preserve margin habitats, e.g. macrophyte beds. (5)
Hydraulic backhoe	Land	'Long-reach' machines available. Capable of working in restricted spaces, e.g. between trees. Good control over depth and therefore finished bed level.	Selective dredging, therefore can preserve selected areas of vegetation / habitat. Does not drag across bank. Usually causes slightly more disturbance and suspension of material than grab. Non-toxic vegetable or synthetic oils should be used in all hydraulic mechanisms. (4)
Grab	Land / Floating	Rivers where selective dredging (sediment removal) is required and or large amount of debris or over sized material is expected. Grab not suitable for channels where relatively uniform channel bottom required (poor control over bed level).	Selective dredging, therefore can preserve selected areas of vegetation / habitat. Does not drag across bank. Spillage often occurs, not suitable for contaminated sediments (3)
Bucket dredger	Floating	Suitable for large wide navigation channels. Can usually only be used to load floating hopper barges and can only work with a barge along side. Dredging action is continuous, production rates typically higher relative to other types of dredger. Effective if dredging to a fixed level and width over long channel lengths. Capital and operation costs are higher than most other types of dredgers.	Dredger is not selective. Over filled buckets can result in spillage and increased turbidity. Spillage can be a problem if the sediment is contaminated. Modifications can be undertaken to reduce spillage. (3)
Cutter-suction dredger	Floating	A uniform bottom level is usually achieved by the continuous dredging process. Sediment is mixed with water and removed through a pipe system to a pipeline on the shore. The mixture is typically pumped to a purpose-built containment area. Mixture can be sprayed directly onto agricultural land if it will bring nutritious or structural improvement. Dredged material can be highly diluted with water. Not well suited to dredging areas with high concentrations of debris or large sediment sizes.	If operated with care spillage and suspension can be very low. Because all material is transported by pipeline there is little disturbance to the bank. (1)

 # - the numbers 1 to 10 refer to level of environmental impact (CIRIA, 1997), with 10 equating to severe impact and 1 to minimal impact.

Silt curtains can be employed to restrict the movement of sediment (this is particularly necessary when dredging contaminated sediment). Fabric curtains such as geo-textiles weighted at the bottom, or air curtains consisting of rising air and water can create a vertical barrier (see CIRIA, 1997 'Inland dredging – guidance on good practice' for more information). Once the dredging is completed, sufficient time should be given to allow re-settlement within the dredged area before the curtains are removed. However, silt curtains are inappropriate for use in many inland waterways, which are too narrow, shallow and uneven for correct and effective operation. In addition, silt curtains will only work in rivers if they are made of impermeable fabric and are sealed tightly to the bed. Otherwise, the river flow may carry the suspended material through the weave of the fabric and under the bottom of the curtain.

Minimise disturbance to riparian / marginal habitats

Disturbance to riparian and marginal habitats can be minimized by consideration of the access points for dredging and choosing an appropriate dredging technique.

Bank side dredging for example should not be undertaken near areas of sensitive riparian habitat, including marginal aquatic habitats such as important macrophyte beds. It should also not be undertaken in areas where bank erosion is extensive or where the soil is soft and or waterlogged. Operation of heavy machinery in such areas can exacerbate erosion and impact on the bank and riparian habitats. In some circumstances it may be necessary to use a temporary access track using geo-textiles and gravel to help minimize the impact on soft or water logged soils.

Floating dredgers are commonly employed in navigation channels where there is often restricted access along the tow path and narrow waterway corridor (the depth of navigation channels will also permit the application of most floating dredges). Such dredging techniques have lesser impact on the banks and terrestrial riparian zone than land based dredgers. However, unloading operations can still have an effect on the bank top. Tugs tow hoppers of dredgings to and from the floating dredger and to an unloading point, from where material is spread on adjacent fields or transported elsewhere by road. Plant and vehicles may cause damage in this area, and mitigation requires careful site selection to avoid sensitive species and habitats, and to address general care in operation and reinstatement of the site afterwards.

Figure 13.3. Floating hydraulic backhoe

Finally, if removal of selected riparian plants is necessary to allow access for machinery, the removal should be kept to a minimum. Any bank side disturbed areas should be re vegetated by planting and seeding with native, locally sourced plant species; and effective erosion control measures should be undertaken until the vegetation has established. Where possible, work should only be undertaken from one bank.

Timing of operation

Operations should not be undertaken at times when aquatic organisms, e.g. fish, are vulnerable (e.g. migratory periods, spawning, and incubation and hatching periods). The timings will generally vary according to fish species and location so check with your local Fisheries Board and relevant Agency for advice.

The timing of operation is also restricted to the winter months (October – March) for several reasons unrelated to fisheries:

- Water temperatures are lower, so there is less risk of deoxygenation when disturbing anoxic sediments;
- River flows are generally higher, so there is more dilution to reduce any temporary water quality impacts;
- There are no nesting birds; and
- Aquatic life is not breeding.

However, as the need for dredging increases with additional boating use, some activities may need to take place outside this season. This avoids an increase in contractor costs (who do not need to increase their capacity if the season is extended) and maintains the quality of dredging activities.

The timing of dredging may also depend on disposal options. Disposal to farm land for example, may only be possible between cropping and when pastures are free of stock.

There should also be some consideration to the frequency of dredging. While the optimum frequency with which maintenance dredging should be carried out is dependant on the nature of the problem and the local site conditions, undertaking infrequent dredging may not always be the best management practice for the environment, and more often than not results in a greater impact. However, increasing the dredge depth (as a means to reduce dredging frequency) will increase the navigable depth which has been shown to reduce boat related impacts, i.e. scour (Eaton *et al*, 2007). Where specific dredging locations within a channel are utilised for maintenance purposes and have been chosen so as not to impact on more sensitive locations, the frequency of dredging should ensure that ‘unplanned’ dredging is not undertaken at other locations.

Finally, within water bodies where the water column is affected by wind (i.e. increased water turbulence and mixing), dredging should preferably be undertaken on calm days at low water to minimise the suspension of sediment into the water column, especially if silt curtains can not be used.

Location of dredged material

Dredgings can be deposited and spread along the fringes of towpaths, providing a nutrient rich material for vegetation growth. Care must be taken however to deposit the material so that washouts into the channel will not occur.

Source control

Problems caused by excessive sediment deposition may be most effectively addressed by reducing the input of sediment from sources within the catchment.

There are many activities / routes which may be responsible for an increase in sediment supplied to a water body, including: cultivated farming practices; forest ditches and roads; mining; floodplain erosion; construction sites and in-channel works; urban runoff etc, which can all result in significant accumulations of sediment within the water body. Many of these sources are outside the control of the navigation authority.

It is the role of the River Basin Management Plan to identify those sectors responsible, and measures to address point source control are not explored here.

13.1 Hydromorphological / ecological effectiveness

Eaton *et al*. (2007) review current knowledge of the recovery times of canal ecosystems after dredging. There is some evidence that recovery rates decrease with existing boat traffic.

Table 13.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed	• Quantity and dynamics of flow	• River continuity	• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	✓	✓

14 PHASED DEWATERING

Where a section of canal is to be dewatered for maintenance activities, opportunities should be sought, where possible, to limit the extent that is dewatered and to stagger the exercise over time. See Figure 14.1 for an example of how works could be phased.

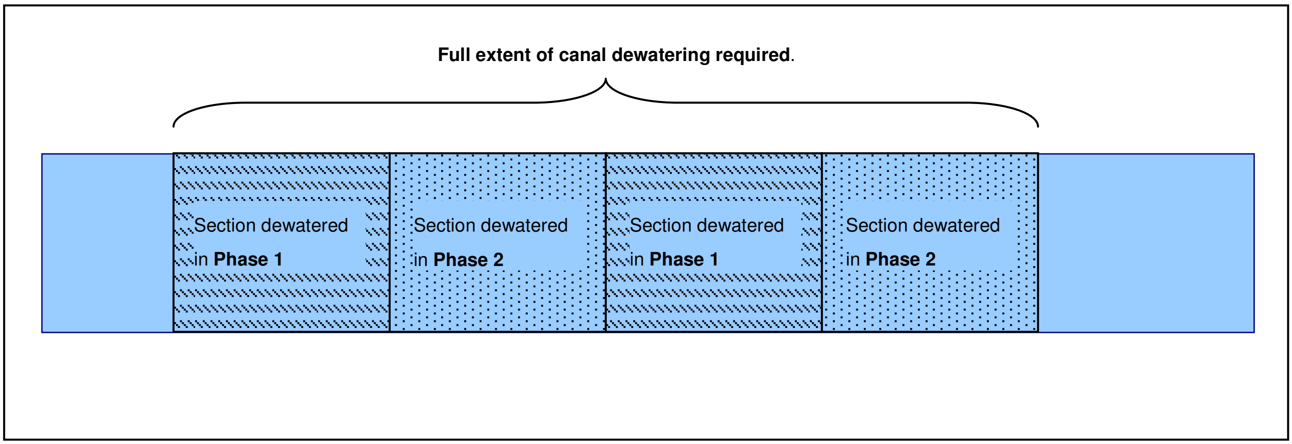


Figure 14.1 . Phasing of canal dewatering exercise.

Phased dewatering dramatically increases the cost of engineering works, making it unfeasible in many cases. However, it may be required if the length of waterway contains submerged macrophytes, which cannot survive without water form prolonged periods. In cases where legally protected submerged macrophytes (e.g. *Potamogeton compressus* and *Luronium natans*) have been encountered, British Waterways has prevented damage using translocation techniques. The plants and sediment in which they are rooted are moved to and adjacent length of waterway, where they are stored for the duration of the maintenance works before being returned once the canal is rewatered.

In England and Wales, it is an offence if fish die when a canal is dewatered, e.g. through lack of oxygen or insufficient water depth. Fish transfer is therefore obligatory in most cases. British Waterways undertakes transfers using electric fishing and netting, and fish are generally transferred to an adjacent length of canal. These activities are licensed under the Salmon and Freshwater Fisheries Act 1975. Legislation in Scotland is not as strict, but British Waterways still transfer fish when required. An annual license for the use of electro-fishing equipment and nets is issued by the Scottish Executive. Where possible, native crayfish are also transferred to adjacent habitat when waterways are dewatered. This is not a legal requirement, although it is included in the British Waterways Biodiversity Action Plan.

Where possible, dewatering should be undertaken in the winter, when much of the channel flora and fauna is in a resting state and therefore less susceptible to damage than in summer. These winter stoppages harmonise with the general operational need to have the canal open for recreational use in summer.

In some circumstances, it may be possible to retain some water in the canal whilst maintenance works are undertaken.

14.1 Hydromorphological / ecological effectiveness

Phasing / staggering a dewatering exercise reduces the amount of time that individual sections are dewatered and, provided that sections are not dewatered concurrently, will increase the likelihood of the whole stretch retaining its associated flora and fauna during the operation.

The hydromorphological effectiveness of this measure is dependent on the duration of dewatering and the nature of the activities that the waterway is being dewatered for. Major maintenance works may have a major impact on hydromorphological quality, for example if they involve physical modification to the channel and substrate. However, this measure is predominantly designed to mitigate the effects of dewatering on aquatic habitats. The preservation and retention of aquatic plants is in itself likely to have a beneficial impact on hydromorphology, for example by preserving existing substrate and providing a degree of natural bank protection.

Table 14.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	?	✓	✓	✓

15 SELECTIVE VEGETATION CONTROL REGIME

Any control program will generally need to be repeated over time to be effective. Before committing to a control program, it is important to weigh up the potential benefits of vegetation removal, against the long-term effects, costs and possible environmental impacts.

It may not always be necessary to remove vegetation from the entire width of the channel. Estimates for the most efficient proportion of the channel width which should be cut, range from 50 to 80%. There is a negligible difference in the hydraulic resistance of a channel when between 80 and 100% of the width is cut, and the benefits decrease proportionally as the cut increases above 50%. Nevertheless, the actual width of the channel section which needs to be cut must be decided for individual sites (Barrett *et al*, 1997).

Many watercourses should not need to be cut more than once each year, although this is strongly dependent on the species that are being treated. For example, species such as water lilies are likely to regrow within a single season. Furthermore, the removal of one problem species may lead to the colonisation by another, which may itself require cutting.

15.1 Hydromorphological / ecological effectiveness

There are several advantages to leaving a proportion of the river uncut:

- The cutting operation is faster with less weed to remove;
- Some marginal habitat is preserved and the environmental impact is reduced;
- Provided that the uncut proportion includes the margins, the remaining weed may protect the banks from erosion;
- Weed across the whole width of the waterway may not be any greater throughout the season than if it was cut and re-grew in a synchronised way;
- Partial cutting allows for some selection of which species are cut and which are left. Retaining some floating vegetation may suppress the growth of submerged vegetation by limiting light penetration;
- Partial cutting can be beneficial for phytoplankton, by increasing the availability of light and nutrients;
- Benthic invertebrates benefit from partial cutting due to increased phytoplankton and the retention of some shelter;
- Fish species benefit from the retention of shelter and the creation of areas of open water (partial cutting is employed as a tool by angling managers); and
- Retaining some vegetation creates flow diversity that will be beneficial to fish and invertebrates.

(Barrett et al, 1997).

It should be noted that partial cutting is not suitable for use with all problem species. For example, water pennywort (*Hydrocotyle* spp.) will quickly re-spread if only partially cleared.

Table 15.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	Hydrological regime	River continuity	Morphological conditions
Effectiveness of measures			✓
Hydromorphological elements addressed			• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	Phytoplankton	Macrophytes	Benthic invertebrates	Fish
Effectiveness of measures	?	✓	?	?

16 APPROPRIATE VEGETATION CONTROL TECHNIQUE

Techniques for aquatic plant removal include mechanical, chemical, biological, and environmental.

Mechanical

Mechanical weed control consists mostly of cutting and pulling. Vegetation management undertaken from the bank side (i.e. use of heavy plant) can potentially result in riparian and marginal vegetation being unnecessarily destroyed, and the bank itself becoming destabilised. This results in increased volumes of sediment entering the water column, and could lead to bank failure. Weed cutting can also lead to the removal of aquatic invertebrates. However, this can be easily mitigated by leaving cut vegetation on the banks prior to its removal, allowing invertebrates to return to the water.

Weed cutting allows more selective vegetation removal, but will tend to be more expensive (i.e. capital costs associated with acquiring the machinery). The most selective measure is to cut by hand; however, this is extremely labour intensive and may be limited to areas where the spread of certain invasive species needs to be avoided. It is not normally feasible in most waterways because there is usually too much weed for it to be effective.

Many conventional mechanical techniques can have a major adverse impact on hydromorphological quality, for example by leading to accelerated bank erosion and potential bank failure. However, techniques such as selective hand picking, boat-mounted apparatus, or the use of a long-reach excavator from a single bank, can be used to minimise the hydromorphological consequences of vegetation removal.

Mechanical cutting using floating machinery is now the method most favoured by British Waterways. The cost of this method can be relatively low when compared with traditional chemical control techniques, particularly when the cost of removing decaying vegetation after it has been sprayed is taken into account.

Figure 16.1. Boat mounted vegetation control (Berkenheger weed boat)

Chemical
Herbicides result in minimal physical disturbance associated with mechanical control. However, their use must consider the potential wider environmental consequences, i.e. herbicides will have limited selectivity, and other uses of the water may restrict their use. Although herbicides that target submerged weeds are available, they can only be used in slow or static waters. The use of herbicides can be costly, and certain plant species may develop a resistance to the treatment itself over time. Furthermore, herbicides can lead to the deoxygenation of the water as the vegetation dies, requiring aeration and further monitoring. It should be noted that the availability of effective herbicides has reduced in recent years, due to the introduction of European legislation such as the Biocides Directive (98/8/EC).

Biological
Once classical biological control agents are successfully established, the control achieved is long-term, requiring little or no further expenditure (CEH, 2007). Fish (such as carp) will eat small plant infestations that are not well developed. However, dense infestations can cause severe fluctuations in the dissolved oxygen content of the water, and subsequent fish mortality.

British Waterways have previously attempted to use grass carp to control weeds on the Lancaster Canal, Bridgwater and Taunton Canal and Chesterfield Canal. These trials were initially highly successful, but after several years the population declined due to lack of food and predation by cormorants. The technique fell into disuse due to the amount of management intervention required. In addition, grass carp are a non-native species, and as such require a license before they can be introduced into a waterway. Consent from the nature conservation regulator will be required if the alien species could escape into a legally protected conservation areas.

Environmental
Shading can be effective if maintained for long periods, for example the retention of some floating vegetation can reduce the growth rates of submerged vegetation through shading. Space permitting, the planting of riparian trees can result in long-term reductions in vegetation growth rates, and reduce the need to for other forms of control (Murgatroyd and Terman, 1983). Furthermore, the planting of trees and hedges along the channel banks to increase shade and decrease plant growth has limited direct impacts on the hydromorphology of the channel (Dawson, 1981; Brookes, 1997). However, the planting of trees along canals is not recommended, since root growth may damage the banks. In addition, excess shade may lead to detrimental effects on macrophyte diversity on canals. Tree planting may therefore conflict with WFD and biodiversity objectives.

16.1 Hydromorphological / ecological effectiveness

Land-based mowing buckets affected the greatest reduction in macroinvertebrate numbers in the immediate aftermath of a cut. This reflects the capacity of the machine to cut vegetation to canal bed level, thereby removing any substrate for colonisation. The Office of Public Works (Ireland) policy of removing obstructive vegetation from a central navigation channel, while preserving weeded marginal fringes, minimises the impact of weed control operations on the macroinvertebrate fauna. (Monahan and Caffrey, 1996).

Monahan and Caffrey (1996), when comparing weed control measures found that for both mechanically cut and herbicide (dichlobenil) treated canal sites, macroinvertebrate numbers increased relatively rapidly following treatment, and no adverse effect on dependent fish life resulted. Most of the weed control procedures operated in Irish canals achieve only short-term (3-4 months) control and are followed by vigorous regrowth of the plant species that were present before treatment (Wade, 1982; Caffrey, 1990b). Where some boat traffic is present, it is more effective to expend effort on thorough clearance of a central navigation channel, leaving the edges uncut, than to use the same effort on a more general, but less complete, reduction in vegetation across the whole width of the channel (Eaton and Freeman 1982).

The use of hydromorphologically-sensitive cutting techniques, such as hand-picking, boat-mounted apparatus, or long-reach excavators can help to considerably reduce the hydromorphological impacts of vegetation management activities. Furthermore, some marginal vegetation can be retained in order to provide some protection against bed and bank erosion.

Table 16.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Channel patterns • Width and depth variation • Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	**?**	**?**

17 APPROPRIATE TIMING OF VEGETATION CONTROL

Work can be timed to avoid sensitive periods in the life-cycles of in-stream and riparian flora and fauna. For example, salmonid species use gravels for spawning in the autumn, egg incubation in the winter and emergence of young fish in the spring. The bird breeding season (mid- March to end July) is another sensitive period that should be avoided. Plant removal in summer or autumn is preferable for benthic invertebrates because the impact appears to be less severe than in spring (Kaenel and Uehlinger, 1999).

Good timing of weed control is also important for achieving the maximum level of control. For example, in some instances the most effective weed control will take place when the weed species is actively growing.

From a hydromorphological perspective, it may be important to avoid undertaking cutting operations during periods when heavy rainfall, and therefore flooding, is likely to occur. This will allow the erosion protection provided by marginal and aquatic vegetation to be maximised, thus reducing the hydromorphological impacts of high flows.

17.1 Hydromorphological / ecological effectiveness

There have been few studies into the effect of aquatic plant cutting on benthic invertebrates, but those studies available have clearly shown the negative impacts (Pearson and Jones, 1978; Monahan and Caffrey, 1996; Kaenel *et al.*, 1998). Invertebrates that rely on macrophytes as habitat are strongly affected, whereas highly mobile taxa or taxa living in the bottom sediments proved to be quite resistant. The long-term recovery of invertebrates is undoubtedly influenced by factors besides macrophyte biomass, current velocity and depth; for instance by the presence of undisturbed reaches upstream and by the timing of aquatic plant removal. It also appears that plant cutting in spring has more severe impacts on stream invertebrates than in summer. This should be considered in future aquatic plant management strategies. If plant cutting is implemented, it should be completed in summer and preferably without destroying too much of the aquatic habitat. This could be easily achieved by leaving some macrophyte beds uncut (Kaenel *et al.*, 1998). In addition, works could be timed to avoid periods of high flow, when the erosive power of water is at its greatest, thereby reducing potential bank erosion.

Table 17.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	**?**	**?**	**?**

18 APPROPRIATE TECHNIQUES (INVASIVE SPECIES)

For some invasive species, for example floating water pennywort (*Hydrocotyle ranunculoides)*, mechanical and chemical intervention may not be adequate and may actually lead to further spread. In these cases hand picking is often used (Trudi Wakelin (Broads Authority), *pers. comm.,* 2007; John Gibson (National Trust), *pers. comm.,* 2007).

In the Chelmer and Blackwater Navigation, a severe infestation was brought under control by an initial mass clearance using machinery, followed by further machine clearances of large surviving re-growths. After this, thorough hand picking each year sufficed (Peter Spurrier, Essex County Council, *pers. comm.,* 2006).

Suction dredging has been tested by British Waterways to address *Azolla* (duckweed) infestation (Centre for Ecology and Hydrology Aquatic Plant Management Group, 2004). *Azolla* was pumped off the top of the water into a container with a filter to remove water. The water was returned to the canal, and when the container was full, it was tipped out and the vegetation was transported away for off-site disposal. This reduced the weight of weed to be removed by about 50-60%. Weight reductions in *Lemna* would be expected to be of the order of 70-80%.

18.1 Hydromorphological / ecological effectiveness

Where alien species are known to be present, measures should be employed that minimise their spread; this will be site and species specific. For example:

- A floating boom can be employed to isolate the working area and prevent the downstream transport of plant material. However, use of this technique may require the introduction of temporary restrictions on navigation in the channel while works are underway.
- Suction dredging, in areas where debris is minimal, is considered to be a particularly effective method of removal for most species of floating aquatic weed (Centre for Ecology and Hydrology Aquatic Plant Management Group, 2004). Dredging should be carried out in a hydromorphologically-sensitive manner, for example by using floating equipment and sediment traps;
- Fragmentation of parrots feather (Myriophyllum aquaticum) must be avoided. Dredging shallow areas will remove the plant effectively, followed by hand pulling stems (Environment Agency, 2003); and
- Hand pulling works very well in small infestations. Chemical treatment does not result in the plant rotting down quickly, and should be followed up by removal in flood risk areas, navigable areas etc. Follow-up spot treatment is recommended after mechanical removal (Environment Agency, 2003).

Table 18.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	**?**	**?**	**?**

19 ENCOURAGE REDUCTION OF BOAT WASH IMPACTS THROUGH TRAFFIC MANAGEMENT IN SENSITIVE AREAS

There have been various studies of the effects of boat traffic on canal ecosystems, mostly carried out at the University of Liverpool over the last 25 years (Murphy and Eaton, 1983; Moodie *et al.*, 2000; Willby *et al.*, 2001). This research shows that boats affect aquatic plants in four main ways:

- Direct physical damage caused by propellers and hulls. At high boat densities there are also indirect physical effects caused by turbidity, which reduces plant growth;
- Boat generated waves and currents causing uprooting and damage;
- Shading of submerged plants by eroded and re-suspended sediments; and
- Soft, unstable and periodically re-suspended silts, preventing colonisation of aquatic plants.

Limiting the movements of boat traffic can therefore help to reduce these impacts on the hydromorphology and biology of the water body, although the ecologically beneficial effects of increasing boat traffic on lightly used canals should also be recognised.

There are no legal mechanisms for limiting boat traffic movements, since British Waterways and other navigation authorities are legally obliged to make their waterways generally available for navigation. However, it may be possible to limit boat traffic movements using indirect means, including controls on the location of moorings and hire bases and the controlled development of local attractions (Moodie *et al.*, 2000).

Instead of limiting the numbers of boat traffic movements, it may instead be possible to minimise the impacts of boat traffic by imposing speed limits in sensitive areas. The rigorous enforcement of speed limits is likely to prove effective in reducing the impacts of boat traffic (Willby, undated). A maximum speed limit of 3 mph in the most sensitive and constricted areas of the Norfolk Broads has been recommended (Boswell, 1997), although it should be noted that these waterways are particularly sensitive to erosion. The maximum speed limit in most UK canals is 4 mph, although this typically increases to 6 mph in most ship canals and navigable rivers. These limits are set in a series of byelaws.

Figure 19.1. Speed limits along the River Ant

19.1 Hydromorphological / ecological effectiveness

A method for predicting the impact of various boat traffic densities on a given canal vegetation has been developed by Willby & Eaton (2002) and is reported in Montgomery Canal Partnership (2005).

Murphy & Eaton (1981) identify a significant relationship between summer abundance of submerged water plants and invertebrate diversity within canals, measured as the number of taxa recorded, at canal sites (surveyed in 1977-78). They concluded that plant-associated invertebrate diversity declined with decreasing vegetation, and hence generally with increasing boat traffic and further suggest that it would appear likely that high densities of boat traffic degrade the invertebrate food base available to fish, especially that part of it which is plant-associated (as opposed to that portion dwelling in bottom sediments).

The number of boat movements per year has been linked to changes in species composition, and, at high traffic densities, to reductions in species diversity (Murphy and Eaton, 1983; Willby *et al*., 2001). Willby and Eaton (2002) (in Montgomery Canal Partnership, 2005) show that between 200 and 600 movements a year can check the dominance of competitive species and hence can have a beneficial affect on species diversity. Consideration should be given to other influencing factors, for example the nutrient-poor Montgomery Canal had the dominance of competitive species checked by lack of nutrients (Eaton *et al*, 2007). A level of boat movements above 600 per year has been shown to have a steadily deleterious affect on species diversity, much more rapidly for submerged and floating-leaved species than for emergent forms (Eaton *et al*., 2007). A reduction of overall boat traffic is likely to markedly reduce the severity of bank erosion and bed scour, and will reduce the level of sediment resuspension. However, these effects are still likely to occur if boat movement is limited, albeit at a reduced impact.

A combination of physical damage to plants and substrate and increased turbidity caused by over 2000 movements will largely confine plants to the margins of the channel, and create extensive damage to the structure of the bed and banks.

Very light traffic is consistent with high species richness, and as such is the best possible scenario for conservation interests. However, this is unlikely to be widely acceptable for most navigation interests. Even in cases where canals have been designated as SSSIs, an absolute limit on boat traffic has not been agreed. Instead, an adaptive management approach has been adopted, in which the impacts of increased traffic volumes are monitored. Therefore, the adoption of a precautionary adaptive management approach for ecologically acceptable boat traffic densities is recommended. The effective monitoring of traffic should form an important part of the adaptive management process (Willby, undated).

The impact of boat speeds on bank erosion has been examined on the Broads. Detailed measurements of boat wash indicate that in the speed range from 4mph to 7mph a speed increase of just 1mph increases the energy transmitted to the bank by a factor of 3.4. These findings led to the Broads Authority reducing its speed limits by 1mph, and they now range from 3mph, in the most constricted and sensitive areas, up to a maximum of 6mph (Boswell, 1997). A decrease in the speed of boat traffic will reduce the energy of the waves caused by boat movement. This will in turn lead to a reduction in the rates of bed scour and bank erosion, undermining and failure that are experienced in sensitive areas.

The Broads Authority findings are confirmed by Verheij (2006), who showed that the hydraulic stresses created by boat movement, especially in small ‘constraint’ channels, are very sensitive to craft speed. A limit of 2 mph has been set on the Montgomery Canal and is predicted from the estimates of Verheij (2006) to provide a hydraulic environment within which plant growth will be possible on the upper parts of the batters of this conservationally important waterway (Eaton *et al.*, 2007).

Table 19.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	?	✓	?	?

20 ENCOURAGE USE OF ENVIRONMENTALLY FRIENDLY VESSEL DESIGN

The concept of sustainable boating is being promoted within the UK. The concept includes:

- Raising awareness of sustainable boat design, technologies (reduced carbon emissions, power sources, novel materials, etc), and environmental best practice (waste handling, boat dismantling, recycling, etc);
- Providing information so that environmental considerations are central in the design, construction and operation of boats; and
- Provide information about the opportunities for reuse, recycling and disposal of whole boats and their components at the end of their life (Landamore *et al*, 2005).

Environmental considerations that can be incorporated into boat design can include:

- Energy efficient hull shape (minimising water disturbance);
- Reduced carbon propulsion systems (such as solar power, electric power, etc); and
- Shrouded propeller (reducing bed scour).

Figure 20.1. Fitting a propeller shroud

Uptake of environmentally friendly boat may be limited (given potential costs implications), as such it would need to be introduced alongside options such as:

- Financial incentives for annual boat licence fees; and
- Licence incentives for hire boats / trip boats / restaurant boats, etc, alongside a degree of compulsion to incorporate such design features. These classes of boat create much more traffic per craft than private boats (John Eaton, *pers. comm.,* 2007).

20.1 Hydromorphological / ecological effectiveness

Consideration of more energy efficient, less disturbing hull shapes and propulsion systems will reduce the level of impact boat movement has upon the system. For example, the use of electric boats (i.e. battery powered) drives a need to maximise efficiency of energy use and hence the creation of minimum disturbance hulls. The Broads Authority is pioneering solar power on Britain's waterways with the introduction of Britain's first passenger carrying solar powered boat (Ra) on the Norfolk and Suffolk Broads. The 30ft, 12 seater boat, which has three rows of seven solar panels, runs trips around the recently restored Barton Broad.

British Waterways sponsored research in the late 80s and early 90s to develop a narrow boat design that generated less wash and less return current around the hull, and therefore less bank erosion. The modification found to be most successful was a modified hull shape (termed an "ecohull"). This resulted in 15-30% less bow wave and 5-10% less stern wave. Shrouding of the propeller was also found to produce less return current. Several narrow boats have been built to this design to date, but have not proved popular.

Given the operational life of boats, it is expected that the existing 'fleet' would be around for some time to come (i.e. decades). As such, incorporating these hull design options into new builds will only take effect in the long-term.

The promotion of shrouded propellers (both in new vessels and as a modification to existing vessels) can also help to mitigate the impacts of navigation activities. A shrouded propeller causes considerably less bed scour and sediment resuspension than an unshrouded propeller. Furthermore, a shrouded propeller will cause considerably less damage to aquatic vegetation. Verheij (2006) suggests that this is a relatively simple modification that can be fitted to existing boats and has considerable potential for reducing hydraulic stresses within the channel.

Table 20.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			**?**
Hydromorphological elements addressed			- Substrate conditions

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	**?**	**?**	**?**

21 BANK REHABILITATION.

Bank rehabilitation is defined as the partial structural and functional return to a pre-disturbance state. Bank rehabilitation could include re-planting of reed beds and aquatic plants, however, rehabilitation is only likely to be effective if the cause of degradation is managed or removed. Monitoring and evaluation of rehabilitation projects is important to determine the effectiveness of the work and allow further action to be taken if required.

Further details of relevant ecological and engineering considerations are provided in Measures 1 (removal of bank reinforcement or replacement with soft engineering solution), and 2 (preserve and enhance ecological value of banks).

The measure is specifically targeted towards addressing impacts associated with boat movement, and, as such the pre-disturbance state refers to pre-boat disturbance conditions, and will typically include measures for appropriate bank protection (see measures 1 and 2). Although this measure is suitable for use in navigable river channels, it may not always be practical for application in wholly artificial watercourses such as canals.

21.1 Hydromorphological / ecological effectiveness

Multiple stressors and impacts affect most aquatic systems that require rehabilitation. This means that actions such as planting reed beds or bank re-profiling are unlikely to lead to successful rehabilitation if conducted in isolation. However, natural vegetation can in some cases be encouraged to colonise suitably reprofiled banks, helping to stabilise the surfaces and minimise the need for additional bank protection.

Table 21.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures		✓	✓
Hydromorphological elements addressed		• River continuity	• Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	?	?	?	?

22 LATERAL ZONING TO CONCENTRATE BOATS WITHIN A CENTRAL TRACK

Temporal (seasonal) zoning of boat movements, is a common strategy on open waters such as reservoirs to reduce disturbance to the most sensitive areas, for example there is a voluntary agreement with boat owners at Horesy Mere (Norfolk Broads) to stay off the Mere during the critical months of the over wintering bird season. This option may only be practical for large or braided channel navigable systems, where it is possible to close off some areas to boat traffic without unduly restricting recreation.

Many UK waterways are, however, too narrow for lateral zoning to be introduced effectively. Canals are frequently 10 m wide, and, once moorings are considered, typically have a navigable channel of only 6 m. This means that the full width of the channel will often be used by boats. However, lateral zoning has been introduced by British Waterways in the recently restored Rochdale and Huddersfield Narrow Canals. These waterways support floating water plantain (*Luronium natans*), a protected species that is particularly vulnerable to the effects of boat movement. In this case, zoning was introduced through the installation of a geotextile barrier or marker stakes to protect the plant communities.

22.1 Hydromorphological / ecological effectiveness

Lateral zoning, for example, concentrating boats within a central track, can reduce damage to marginal communities. It is particularly effective in areas where there are known sensitive communities. Lateral zoning could also hep to avoid damage to the banks, by leading to a reduction in the intensity of boat wash and a corresponding decrease in erosion. Furthermore, established marginal vegetation communities are better able to absorb some of the erosive power of bow waves, helping to protect the banks from erosion.

Table 22.1. Summary of WFD indicators met and hydromorphological elements addressed by this measure

WFD indicators (hydro-morphology)	**Hydrological regime**	**River continuity**	**Morphological conditions**
Effectiveness of measures			✓
Hydromorphological elements addressed			• Substrate conditions • Structure and condition of riparian zone • Quantity and structure of substrate

WFD indicators (biology)	**Phytoplankton**	**Macrophytes**	**Benthic invertebrates**	**Fish**
Effectiveness of measures	**?**	✓	**?**	**?**