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Freshwater Morphology POMS Study

Work Package 2

Programme of Measures to Address Morphology Pressures

REVIEW OF BEST PRACTICE MEASURES

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TABLE OF CONTENTS

Page no.

EXECUTIVE SUMMARY

1.0 Introduction

1.1 This review was undertaken as part of the Freshwater Morphology POMS Study and forms the second part of Work Package 2: *Channelisation Recovery Assessment*.

1.2 The report firstly considers best practice approaches with regard to future river channelisation works including both capital and maintenance schemes. The second part of the report identifies and reviews a series of specific measures to address the key morphological pressures identified in the Article 5 Pressures and Impacts Analysis.

2.0 New Perspectives on Channelisation

2.1 It is considered that new drainage schemes with the aim of increasing agricultural output are unlikely to be undertaken in the foreseeable future, but there is a statutory requirement for maintenance of existing schemes. There is also likely to be a need for flood protection schemes involving localised channelisation works.

2.2 An environmentally sensitive approach to channel works is proposed through the adaptation of techniques to meet the objectives of both engineering function and habitat protection. This approach acknowledges the importance of natural channel form and fluvial processes in the development of physical habitat diversity.

3.0 Strategy

3.1 A strategy is outlined for future schemes based on proposals by O'Grady & Curtin (1993), with an integrated approach at the planning stage to involve a multidisciplinary project team of engineers and environmental specialists in different fields. The project team should be able to adjust scheme design to the advantage of fisheries and other wildlife interests, while still achieving the original drainage or flood relief objectives.

3.2 A series of sensitive working practices is outlined including the retention of natural features and single bank working. Measures to accommodate fisheries interests during scheme works are also described with regard to the scheduling of works, the control of silt loads, fencing of channels and the disposal of excavated materials.

4.0 Rehabilitation and mitigation

4.1 It is recommended that instream rehabilitation works be delayed for a period of 2 years after capital works to observe how channel morphology is adjusting, so that a rehabilitation scheme can be designed to accelerate recovery by working *with* natural channel forms and processes.

4.2 The potential application of the *No Net Loss Principle* is discussed as a means of mitigating losses when standard mitigation measures may be insufficient to offset environmental damages caused by channel works in a particular area.

5.0 Maintenance of drained channels

5.1 The Arterial Drainage Act 1945 requires that drainage scheme channels, flood embankments and associated structures are maintained *in proper repair and effective condition*, to ensure the free flow of water in rivers and to provide an adequate outlet for land drainage.

5.2 Machine maintenance works, by their very nature, will alter river morphology to some degree, and will have the potential to adversely affect ecological status as defined under the Water Framework Directive.

5.3 It is acknowledged that the Office of Public Works (OPW), in conjunction with the Central Fisheries Board (CFB), has developed an advanced environmental approach to maintenance works through the Experimental Drainage Maintenance (EDM) programme. This programme has identified 10 environmentally sensitive protocols which have become the guiding principles for maintenance works on Irish rivers.

5.4 It is recommended that the environmental standards adopted by OPW are also applied in the case of Drainage Districts, for which Local Authorities have maintenance responsibility.

5.5 The procedure for drawing up the Annual Works Programme for maintenance is outlined. Maintenance is generally carried out every 4 years on the typical, relatively small Irish channel, while larger, main-stem channels tend to be maintained on a 6 to 15 year cycle.

5.6 There is clearly a degree of inconsistency between the maintenance standards required by the 1945 Act and the status objectives of the Water Framework Directive, even with the adoption of environmentally sensitive protocols during maintenance works.

5.7 It is recommended that environmental considerations should be included in the decision making process as to whether or not maintenance works are required in a particular reach. In this way, the higher the environmental sensitivity of a watercourse, the greater the attention needed in justifying the works and in choosing the methods to be used.

6.0 Measures to address morphological pressures

6.1 The significant morphological pressures on waterbodies as identified through the Article 5 Pressures and Impacts Analysis were:

- ***Channelisation and flood embankments***
- ***Impoundments and regulation***

- ***Intensive land use***

The Freshwater Morphology POMS Study is also investigating the impact of instream structures obstructing species migration and affecting continuity, under the heading:

- ***Barriers to migration***

6.2 The measures to address the impacts of each of the above pressures are:

(Channelisation and flood embankments)

1. Re-meandering of straightened channels
2. Narrowing of channels
3. Re-construction of pools
4. Substrate enhancement
5. Fencing programmes to exclude livestock
6. Removal or re-location of flood banks
7. Application of OPW Environmental Drainage Maintenance guidelines
8. Incorporation of river restoration & fisheries enhancement projects
9. Measures to facilitate natural recovery
10. Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution
11. Re-opening of existing culverts

(Impoundments and regulation)

12. Removal of structure and de-silting of impounded reach
13. Adoption of operational protocols

(Intensive land use)

14. Stabilisation of river banks
15. Application of Rural Environment Protection Scheme (REPS) special measures
16. Fencing programmes to exclude livestock
17. Application of best practice forestry guidelines
18. Operation and maintenance of silt traps at peat extraction sites
19. De-silting of affected river reaches
20. Incorporation of Sustainable Drainage Systems (SuDS)

(Barriers to migration)

21. Removal of structures
22. Structural modification - construction of fish passes etc
23. Adoption of operational protocols

6.3 An analysis of each measure is presented with comments on application, benefits, feasibility and effectiveness.

6.4 The appropriateness of each measure should be assessed when drawing up the Programme of Measures for each waterbody.

1.0 BACKGROUND

This review forms part of the Freshwater Morphology Programmes of Measures and Standards (POMS) Study undertaken by the Shannon International River Basin District according to the Terms of Reference agreed in October 2005. This particular aspect of the POMS Study was carried out as part of Work Package 2: *Channelisation Recovery Assessment*.

An initial report under this heading (Document no. DC096) outlined the impacts of channelisation on river morphology and ecology, with an emphasis on the recovery of fish populations, while also considering recovery of the aquatic community in general, with particular reference to benthic macroinvertebrates and aquatic macrophytes. This current document is supplementary to the initial report completed under Work Package 2.

2.0 INTRODUCTION

The key objectives of the EU Water Framework Directive (WFD) in relation to freshwater morphology are:

- to achieve at least *Good Status* in all waters by 2015
- to prevent deterioration of status in all waters, and to maintain *High* and *Good Status* where they exist

Article 13 of the WFD stipulates that River Basin Management Plans will be developed including detailed Programmes of Measures (PoMs), formulated as packages of risk management and improvement actions designed to achieve the above status objectives. PoMs will consist of both basic and supplementary measures – basic measures will be essentially legislative and regulatory, while supplementary measures may also include practical measures such as codes of practice, voluntary agreements and rehabilitation programmes.

Morphology pressures have been identified across many EU member states as exerting significant pressures, which might result in waterbodies failing to achieve their WFD status objectives. The initial report under Work Package 2 indicated that channelisation in the form of past arterial drainage schemes has had significant and long term impacts on river morphology and ecology in Ireland, and that on-going maintenance works continue to be disruptive in this respect.

This supplementary report firstly considers best practice approaches with regard to future river channelisation works including both capital and maintenance schemes. The second part of the report identifies and reviews a series of specific measures to address the key morphological pressures identified in the Article 5 Pressures and Impacts Analysis.

A separate *Policy and Legislation Review* completed under Work Package 1 outlines the legal mechanisms in place for delivering these measures and identifies legislative and policy gaps that need to be addressed in the context of freshwater morphology.

3.0 NEW PERSPECTIVES ON CHANNELISATION

3.1 The future of river channel works in Ireland

Changes in EU policy over the last 25 years, combined with increased environmental awareness, would suggest that new drainage schemes with the aim of increasing agricultural output are unlikely to be undertaken in the foreseeable future. However, the statutory obligation requiring the Office of Public Works (OPW) to maintain channels drained under the 1945 Act remains and has the potential to result in significant morphological changes to rivers according to the frequency and extent of the works required.

In addition, the increased incidence of serious localised flooding events in recent years has led to a number of flood relief schemes being undertaken by OPW, most of which have required localised channelisation works. Changes in climate affecting patterns of rainfall are predicted to increase the risk of this type of flood event, and therefore the need for flood protection schemes involving both channel works and the construction flood embankments.

Therefore, while it currently appears unlikely that large-scale channelisation in the form of arterial drainage schemes will be undertaken in the future, morphological pressures on rivers will remain from maintenance of existing drainage schemes and from flood relief initiatives. Beyond this it is likely that there will be occasional requirements for localised channel works on a smaller scale in relation to road works, bridge construction and associated channel realignment.

3.2 The design-with-nature concept

As it has become recognised internationally that the conventional engineering works associated with channelisation can have many negative impacts, there has been a growing interest in alternative approaches that might be applied to provide drainage/flood relief while minimising environmental consequences. Moreover, there is now a greater understanding of river geomorphology and fluvial processes, which allows for a new approach in the design of channel works in order to cause less environmental damage than through conventional approaches. This has resulted in a move towards the need to work *with* rather than *against* a river, and to minimise the aesthetic degradation of the river channel and its surrounding environment (Brookes, 1989).

This approach is in line with the *design-with-nature* concept first proposed by McHarg (1969) who initially suggested that aspects of nature in cities could be improved through watershed (catchment) planning. In time this led to a move away from *hard* engineering design solutions towards a *softer* management approach that mimicked the landscape’s natural characteristics (Brookes, 1989). This idea was later extended to river channelisation through a recognition that engineered rivers, like roads, are transporting systems that must be designed to carry a certain load (flood frequency) compatible with natural channel morphology as well as sediment size and concentration (Keller, 1975). It follows therefore, that channel design should incorporate morphological features and processes that duplicate nature.

3.3 Engineering objectives and habitat protection

Ward *et al* (1994) have discussed how river management techniques can be adapted to meet the objectives of engineering function and habitat protection. They propose that new river channel works, whether in the form of drainage schemes or flood relief, need to work towards retaining or returning a river to a more natural regime, thereby reducing the need for future engineering. Where river works are essential, as is usually the case with flood relief schemes, the authors suggest that the best solution can often be achieved by imitating natural systems, in terms of channel form and processes. It is also noted that treating the causes rather than the symptoms is likely to be both cost-effective and more environmentally acceptable – for example, downstream channel problems may be the result of a change in upstream land use.

If possible within the scope of a scheme, it is important to retain morphological diversity and natural habitats, although in practice this is unlikely to be fully attainable. If a river channel bed needs to be lowered to achieve drainage benefits or flood relief, it will not be feasible to retain instream habitats, but destruction of riparian habitats can be minimised. The alternative option is to create new habitats during the scheme and/or to carry out a rehabilitation programme after completion of the works.

Habitat retention, rehabilitation or creation all require an understanding of the river processes which shape habitats for plants, invertebrates and fish (Ward *et al*, 1994). Some key concepts for consideration in integrating the objectives of both engineering function and habitat protection/enhancement are outlined in Table 1.

• Energy	The primary hydraulic forces in all streams which shift and deposit bed materials to form morphological features. These forces should be used creatively.
• Straight channels	Rarely exist in nature and should be avoided if possible. Tend to be high energy and may self-adjust by erosion towards formation of meanders.
• Habitat	If works are essential, this may be used as an opportunity to protect, rehabilitate and create wildlife habitat.
• Space	Maximum environmental gain usually requires maximum space. A natural channel is inefficient in spatial terms in comparison to an engineered trapezoidal channel. Where possible the channel should be given space to adjust naturally within generous buffer zones.
• Simulate	Pre-works surveys will indicate positive habitat features; these should be simulated during scheme works using indigenous plants and materials.
• Extremes	Consideration of how the channel will function under extremes of flood and drought should be included in design.

Table 1 Basic concepts for integrating engineering and wildlife needs (Adapted from Ward *et al,* 1994)

3.4 A modified approach to channelisation

It is clear that many of the negative environmental impacts of channelisation can be avoided through channel design to minimise disruptions to existing fluvial and biological systems, and by the incorporation of environmental features into channel design (Nunnally & Shields, 1985). Environmental features may be regarded as mitigation measures in the form of any structures or actions employed in the planning, design, construction, or maintenance of drained channels, that produce environmental benefits.

An environmentally sensitive approach to channelisation is essentially a two-stage process:

1. Incorporation of environmental features or mitigation measures into scheme design to offset environmental impacts at the outset
2. Post-works enhancement schemes with the same objective.

Alternative approaches to river management have been developed by geomorphologists, recognising the river as an open system in which there is a balance between channel form and channel processes, consistent with the concept of *geomorphic engineering* as proposed by Coates (1980). This approach recognises that the river is ultimately the best restorer of its natural morphology and should be allowed to participate in its own recovery – the channel is designed according to the broad dimensions of the river, and then the river itself is left to develop the intricate cross-sectional detail and intra-reach morphological features to complete the recovery process (Soar & Thorne, 2001). Through this approach the types and levels of physical habitat diversity that are sustainable in a particular channel reach are defined by the type of river, the nature of the sediment and flow regimes and the catchment context.

3.5 An inclusive strategy

O’Grady & Curtin (1993) have drawn up a proposed strategy on how drainage engineers and fisheries biologists might work together to ensure that drainage schemes on salmonid catchments will have minimum impacts on the functioning of river channels in relation to fisheries interests. Although this strategy focuses on fisheries interests and salmonids in particular, it serves as a useful model for an overall environmental approach to channelisation type works. The key elements of the strategy are outlined here and supplemented from other sources.

3.5.1 A multidisciplinary approach to design

In order to properly address environmental issues relating to a proposed scheme, it is important to adopt an integrated approach at the planning stage involving a multidisciplinary project team of engineers, hydrologists, geomorphologists, landscape architects, fisheries biologists and specialists in other aspects of wildlife conservation (Ward *et al*, 1994). The involvement of these different disciplines at the planning stage is crucial in ensuring that the scheme design takes account of environmental factors so that it will have minimal impacts on river morphology and ecology.

A full baseline survey of the river corridor and floodplain will be required to understand the ecological significance of particular reaches and areas, and to predict the likely effects of the works through an environmental impact assessment. This process should include the following:

- River Morphology Survey
- River Corridor Survey
- Plant Surveys
- Otter Surveys
- Bird Surveys
- Fish Stock Surveys
- Amphibian and Reptile Surveys
- Invertebrate Surveys

In the initial stages of a drainage scheme proposal, detailed studies are completed to prepare an engineering design outline – the physical and hydrological data generated in this process are of particular interest to fisheries biologists as it will assist with the identification of different channel types according to gradient and substrate type.

3.5.2 Adjustment of scheme design

At this stage there are often a range of engineering options available to achieve the same objectives and the project team will be able to discuss which options will minimise adverse impacts and therefore be of benefit to wildlife. It should therefore be possible for the team to adjust the initial design to the advantage of fisheries and other ecological features, while still achieving the original drainage or flood relief objectives. This approach is usually very effective in relation to fisheries, but generally results in additional engineering costs. However these costs must be balanced against the long term potential damage to fish stocks and other forms of wildlife. Important considerations at this stage include:

Retention of natural features

As already noted, it is important that natural features of the channel such as meanders, riparian vegetation and bank slope should be retained where possible.

Single bank working

Operating excavators from one bank only has become a widely accepted practice in channel works, provided the drainage objectives can be achieved in this way. It may be desirable to preserve one bank in a particular zone on the basis of the habitat value of its vegetation, aesthetics, shade and bank stability. However, this should normally restrict disturbance to the northerly bank in order to preserve channel shade from the opposite bank. Where there is significant removal of the riparian zone it should be re-planted as a priority.

Channel widening

If significant widening of the channel is required to meet drainage objectives, it is important that the design should be adjusted to incorporate a low flow channel within the main channel to accommodate summer flows which allow for adequate water depth. This can be accomplished through the construction of a two-stage channel or multi-stage channel.

Lowering of high points

In some cases scheme works will require the removal of high points in the longitudinal profile, usually in the form of lowering of bedrock protrusions. This may provide an opportunity for mitigation or enhancement through the creations of pools, or in the exposure of new shallow areas which may be potentially productive areas for juvenile fish. Careful adjustment of scheme design will ensure that these benefits can be maximised.

3.5.3 Accommodating fisheries interests during scheme works

Works schedule

Studies of the impact of drainage on Irish rivers have indicated that there is a collapse of fish stocks immediately after the completion of works. O'Grady & Curtin (1993) have recommended some key points with regard to the scheduling of works in a catchment if all channels are to be subject to works:

- the lower third of each channel should be excavated first with the machines then moving in an upstream direction
- the length of each channel excavated should not exceed one third of the channel length in one year
- some key spawning and nursery grounds, and adult fish feeding areas should remain unaltered for at least 3 years while areas drained initially are recovering

Controlling silt loads

Channelisation operations can generate significant levels of silt from in-channel works, bank-works and the movement of machinery adjacent to the river. In each scheme a strategy should be devised to minimise the direct input of silt to the river. This may involve the construction of silt traps within each sub-catchment to reduce the input of silt from disturbance to surrounding land. The regular maintenance of silt traps during the programme of works is important, and they may be required after completion of the works until banks have stabilised adequately.

Fencing

It has been OPW policy to fence off channels after drainage works and the evidence is that, where these fences have been suitably maintained, a healthy riparian zone has regenerated. There is therefore a clear advantage in the fencing off of channels after engineering works to exclude livestock, and this should be carried out in the case of all channel works. Re-seeding of banks with grass and re-planting of trees is also helpful in regeneration of the riparian zone.

Disposal of excavated materials

Channelisation works usually produce excess materials which may have to be removed from the site or *lost* within the area of the works. Large quantities of stone may be required for post-works rehabilitation measures and it may be possible to stockpile excavated rock and gravel for use in these subsequent works. This will reduce the costs of the rehabilitation programme.

Insensitive disposal of materials may be harmful to wildlife, and safe disposal is therefore an important environmental consideration. For example, it has been common practice to dispose of materials by filling in low spots in adjacent land, but these can often be wetland areas which may contain plants and invertebrates, and can be breeding areas for amphibians and birds. It is therefore suggested that the pre-works planning process should identify areas suitable for disposal of materials and areas that should be avoided.

3.5.4 Post-works rehabilitation programmes

General approach

Apart from the fencing of riverbanks and re-seeding/re-planting exercises, O'Grady & Curtin (1993) recommend that instream rehabilitation works be delayed for a period of 2 years after capital works because:

- recovery of the river channel is dependent on a range of morphological and hydrological factors and, while certain predictions can be made, the precise response of the channel will not be known until some time has elapsed post-works
- there are likely to be large quantities of silt in the channel for a period post-works, but this material should be largely scoured out by winter floods
- after 2 years it should be possible to determine the likely long term contribution of bank erosion to the recovery of channel morphology in the form of sand, gravel and stone materials
- in channels of gradient 0.16% - 0.4% some element of recovery in morphology is usually discernible after 2 years with the re-establishment of a limited thalweg and riffle-glide-pool sequence in shallow areas
  (thalweg: the down-channel course of greatest cross-sectional depth)

After this period of time it should therefore be possible to observe how channel morphology is developing and to design a rehabilitation scheme to accelerate recovery by working with natural channel forms and processes.

Devising the rehabilitation programme

There is now a wealth of experience on the application habitat rehabilitation methods on drained catchments in Ireland, and the effectiveness of such schemes has been verified through a series of monitoring programmes in different systems (O'Grady, King & Curtin, 1991; Lynch & Murray, 1992; Kelly & Bracken, 1998; O'Grady, Delanty & Igoe, 2002; O'Grady, 2006; O'Grady & O'Leary, 2007).

A series of techniques are described in the above reports/publications, most of which have been developed in North America, and some of which have been adapted to suit Irish conditions. These techniques are now well-established in the planning of rehabilitation programmes and there are several useful manuals outlining the different methods including

Ward *et al* (1994), Summers *et al* (1996), APEM (1996). The most up-to-date guide which outlines the various techniques in detail and deals specifically with Irish waters is by O'Grady (2006).

The use of these procedures in addressing the impacts of channelisation and other morphology pressures is summarised in the second part of this report.

3.6 Mitigation through the *No Net Loss Principle*

The approach to river channel works outlined above describes a process for the mitigation of damages through sensitive design and including measures for habitat protection, creation and rehabilitation. However, it would appear that localised channel works are more likely particularly in relation to operations such as road works, urban flood relief, bridge construction and associated channel realignment. These developments will almost certainly involve some degree of hard engineering, major alterations to channel morphology and permanent losses to the catchment, albeit on a localised scale. In such cases, application of the *No Net Loss Principle* may be appropriate in order to mitigate such losses.

This mechanism has been applied, mainly in the US, in situations where the use of standard technical solutions and mitigation measures are not sufficient to offset environmental damages caused by development works. The no net loss principle, recently outlined by Barry (in press), accepts that on occasion there will be unavoidable loss to habitats due to developments which are deemed to be in the public interest, but that there should always be compensatory gains built in to ensure that there is no net loss of habitat to the system. This approach has been adopted by the South Western Regional Fisheries Board with regard to proposed developments within its area of jurisdiction.

In the US the process has moved to a situation in which works are carried out in advance by the private sector to enhance the environment. This creates a *bank* of positive developments which can then be *sold* to developers as *credits* which can be applied where particular developments cannot ensure *no net loss* within their sites.

The latter development may be some distance away from practical application in Ireland, but the principle of mitigating losses caused by channel works in one area of a river, by carrying out enhancement works at another location on the same river may be a suitable means of avoiding deterioration in ecological status.

3.7 Maintenance of drained channels

3.7.1 Background

The Arterial Drainage Act 1945 requires that drainage scheme channels, flood embankments and associated structures are maintained *in proper repair and effective condition*, to ensure the free flow of water in rivers and to provide an adequate outlet for land drainage. This statutory obligation is achieved through the use of hydraulic excavators to remove silt and excessive vegetation, repair bank damage, and remove obstructions such as trees encroaching at low levels on the banks. Obviously any intervention of this nature will alter river morphology to some degree and will have the potential to adversely affect ecological status as defined under the Water Framework Directive. Indeed it has long been recognised that maintenance operations can be potentially more disruptive to fish life than the original capital works (McGrath, 1985).

3.7.2 Environmental approach

To examine in detail the impacts of maintenance works the OPW has worked closely with the Central Fisheries Board (CFB) and Regional Fisheries Boards (RFBs) through the Experimental Drainage Maintenance (EDM) programme, 1990-2007, summarised in the initial WP2 report (Document no. DC096). This programme has led to the development of an environmentally sensitive approach to maintenance which includes:

- extensive liaison with statutory stakeholders
- environmental training for machine operational staff
- environmental working practices
- annual work programme to accommodate fish spawning
- enhancement of fisheries during maintenance works

The programme identified 10 alterations to previous working practices which have become the guiding principles for environmentally sensitive maintenance on Irish rivers (details are outlined in the second part of this report).

A GIS database has now been set up based on the original drainage scheme maps and will be used as a basis for management of the maintenance programme. It is envisaged that the database will incorporate information on fisheries, designated areas (SACs etc), and other specialist details on protected species and their habitats.

This advanced approach to maintenance works has ensured minimum disturbance to river and riparian habitats with measures to facilitate channel recovery and instream restorative works to benefit fisheries.

3.7.3 Developing the environmental approach

In the final report on the EDM programme King & Wightman (2006) listed a series of issues which might be considered by OPW with regard to the drainage maintenance programme. These issues, which relate to both fisheries and to the wider ecology of the river corridor, clearly have the potential to further reduce the impact of maintenance operations on river morphology and ecology:

Compliance by machine operators

Observations by CFB staff have revealed a generally good level of compliance by drivers/machine operators with the 10 environmental protocols, but potential for improvement with regard to specific aspects.

New training protocols

Formulation of a second phase of environmentally sensitive maintenance work practices and training programme to take account of new environmental legislation - would involve additional consultations with the National Parks and Wildlife Service (NPWS) and Non-Governmental Organisations (NGOs) involved in countryside issues and habitat sustainability.

Impacts of spoil placement

Targeted study on impacts of spoil placement on biodiversity of riparian/bankslope flora.

Hydraulic and ecological impacts

Targeted study in terms of gains and losses to assess the ecological impacts of maintenance in relation to hydraulic benefits.

3.7.4 Drainage Districts

OPW does not have responsibility for maintenance of the small-scale standalone drainage schemes (Drainage Districts) carried out prior to the 1945 Act. In this case maintenance responsibility rests with Local Authorities although OPW has a policing role including duties to inspect the condition of these schemes. Clearly it is important that the environmental standards adopted by OPW are also applied in the case of Drainage Districts.

3.7.5 Additional considerations

Frequency and degree of maintenance on individual channels

Beyond the above suggestions there may be some merit in reviewing the frequency and degree of maintenance which has been outlined by Gilligan (*pers comm*). At present, maintenance works are carried out according to an Annual Works Programme which is drawn up each year and takes account of:

- History of works – analysis of records, when last maintained, when maintenance is likely to be needed etc.
- Site inspections to assess maintenance requirement
- Representations from landowners
- Additional observations by staff

OPW field staff tend to work within one region and build up an extensive knowledge of the channels of that region. This experience combined with interactions with landowners, RFBs and other stakeholders, enables staff to build up a detailed knowledge of individual channels and the rate of maintenance required.

Operational efficiencies are also a factor to the extent that some channels not immediately requiring maintenance may be included in the Annual Works Programme to reduce the inefficiencies of excessive machine mobilisation.

As a general rule, OPW has found that maintenance is required on average every 4 years on the typical relatively small Irish channel, and this gives the best balance between the extent of maintenance works required and the possible impact on the environment. Too long an interval leads to a need for more extensive works while, with too short an interval, intervention is more frequent, little work may be required and the programme becomes inefficient. Larger, main-stem channels tend to be maintained on a 6 to 15 year cycle as many are self cleaning and therefore have a lower maintenance requirement.

Review of criteria for maintenance works

There is clearly a degree of inconsistency between the maintenance standards required by the 1945 Act and the status objectives of the Water Framework Directive. Although major advances have been made in the development and adoption of environmentally sensitive protocols with regard to maintenance works, the potential for intermittent disruption of river morphology and ecology remains, with the possibility of equivalent temporary deterioration in ecological status as defined by the WFD.

The economics of the maintenance programme have been reviewed through a detailed measurement of return on investment (Anon, 1999). This study, which took into account a range of qualitative factors including impact on the environment and fisheries, calculated that the value obtained from the maintenance programme in 1998 was €1,201m. Over a 50-year timescale, with a discount rate of 5%, this produced a cost-benefit ratio of 1 : 14, indicating a very high return on investment. Clearly this represents excellent value for money, although an updated analysis may demonstrate a less favourable position, but it is likely that the programme is still providing a good return on investment.

It would therefore be difficult to argue on economic terms that maintenance standards should be reduced. However, if the continued application of the programme according to current requirements represents a significant risk to ecological status, it may be necessary to further raise the profile of environmental factors in the selection criteria for maintenance works in any particular reach. To this end the Rivers Agency in Northern Ireland is currently reviewing their guidance manual on maintenance works (Rivers Agency, 1999), the objective being to include both drainage considerations and environmental considerations within the decision making process as to whether or not maintenance works are required. The underlying principle in this process is: the higher the environmental sensitivity of a watercourse, the greater the attention needed in justifying the works and in choosing the methods to be used. Environmental considerations will therefore form part of the decision making process instead of being addressed after a watercourse has already been earmarked for maintenance works. It is recommended that this approach be considered in the Republic of Ireland (RoI) with regard to the selection of river reaches for maintenance works.

4.0 MEASURES TO ADDRESS MORPHOLOGICAL PRESSURES

4.1 Introduction

Alterations to river channels have been carried out in Ireland with different objectives ranging from land drainage, flood protection and river regulation, to impoundment for water supply, water power or hydroelectric development. These activities have resulted in direct changes to natural river morphology while changes in land use have produced indirect impacts on river morphology mainly through increased silt run-off and sediment transport.

These physical alterations or morphological pressures have been identified in the Article 5 Pressures and Impacts Analysis, and subsequently refined as follows:

- **Channelisation and flood embankments**
- **Impoundments and regulation**
- **Intensive land use**

In addition the Freshwater Morphology POMS Study is investigating the impact of instream structures obstructing migration and affecting continuity, under the supplementary heading:

- **Barriers to migration**

These pressures and resultant impacts are presented in Tables 2 and 3 along with specific measures to address each impact. The subsequent analysis of individual measures comments on the application, benefits, feasibility and effectiveness of these measures.

A full description or specification for the various measures is not included here, but appropriate references are noted in the text.

Pressure	Sub-pressure	Impact	No.	Measures	
Channelisation & Flood embankments	Channel alteration - straightening, deepening, widening of channel	Loss of morphological and ecological diversity	1	Re-meandering of straightened channels	
			2	Narrowing of channels	Assisted natural recovery
			3	Re-construction of pools	
			4	Substrate enhancement	
		Loss or impairment of riparian zone	5	Fencing programmes to exclude livestock	
	Flood walls and embankments	Reduced floodplain area/ loss of riparian zone and marginal habitats/ reduced connectivity with floodplain/ entrapment of sediments	6	Removal or re-location of flood banks	
	Drainage maintenance works (dredging and control of vegetation)	Loss of morphological and ecological diversity Disturbance of riverbed and banks/ mobilisation of sediments/ loss of instream and riparian vegetation	7	Application of OPW Environmental Drainage Maintenance guidelines	
			8	Incorporation of river restoration & fisheries enhancement projects (see Measures 2-4)	
			9	Measures to facilitate natural recovery	
	Hard protection - sheet piling, vertical walls	Loss of riparian zone and marginal habitats / loss of lateral connectivity / loss of sediment input	10	Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	
	Culverts	Loss of morphological diversity and habitat	11	Re-opening of existing culverts	

Table 2 Summary of Pressures, Impacts and Specific Measures: **Channelisation & Flood embankments**

Pressure	Sub-pressure	Impact	No.	Measures
Impoundments & Regulation	Dams & weirs	Loss of morphological and ecological diversity in impounded reach / Reduction in productivity / Accumulation of sediment upstream / Loss of sediment input downstream	12	Removal of structure and de-silting of impounded reach
		Inadequate residual flow downstream	13	Adoption of operational protocols
Intensive land use	Over-grazing & bank trampling	Bank erosion/ over-widening of channel/ sediment deposition in watercourses Loss of riparian zone	14	Stabilisation of river banks
			15	Application of REPS special measures
			16	Fencing programmes to exclude livestock
	Forestry operations	Increased run-off rate through drainage systems / silt deposition in watercourses / shading effects	17	Application of best practice guidelines
	Peat extraction	Peat silt run-off and deposition in watercourses	18	Operation and maintenance of silt traps
			19	De-silting of affected reaches
	Hard surface run-off - urban drainage, roads etc	Run-off of silt and deposition in watercourses Increased peak flows Bank erosion	20	Incorporation of SuDS processes
Barriers to migration	Dams, weirs, bridge aprons, & culverts	Lack of continuity Obstruction to migration of fish and invertebrates	21	Removal of structures
			22	Structural modification - construction of fish passes etc
			23	Adoption of operational protocols

Table 3 Summary of Pressures, Impacts and Specific Measures: **Impoundments & Regulation; Intensive land use; Barriers to migration**

4.2 PRESSURE: CHANNELISATION & FLOOD EMBANKMENTS

The impacts of river channelisation and the construction of flood embankments have been detailed in a separate report (Document ref DC096).

4.2.1 SUB-PRESSURE: Channel alteration - straightening, deepening, widening of channel (a)

IMPACT: Loss of morphological and ecological diversity

4.2.2 SPECIFIC MEASURES:

<u>Measure 1 Re-meandering of straightened channels</u>

Outline: Reconstruction of river channel to meandering course by excavation of new channel, as opposed to increasing sinuosity within the existing straightened channel. Stream can be diverted into original channel or completely new route.

Benefits:

- Restoration of stream sinuosity which creates and retains riffle-pool-glide sequence
- Restoration of habitat diversity
- Reduction of gradient may be beneficial in some cases
- Increases length of watercourse and therefore expands overall wetted area
- Potentially more sustainable than instream structures

Application: Streams which have been straightened

Channel diversions to facilitate road building, industrial development etc

Feasibility: Unlikely to be feasible in most cases due to excessive costs and other issues e.g. drainage capacity, flooding of land, land ownership

Feasible on small scale in case of stream diversions or stream enhancement where land is in public ownership.

Effectiveness: Potentially very effective if executed in suitable areas such as original pre-channelised course.

Specification/Description: RRC Manual (2002); Brookes (1987, 1992); Brookes & Shields (1996); O’Grady (2006); Summers et al (1996); Ward et al (1994)

Measures 2-4 Assisted natural recovery

Measures 2-4 are generally described in the literature as *Prompted recovery* (Downs & Thorne, 2000) or *Assisted natural recovery* (Newson et al, 2002) – the use of instream structures to influence flow hydraulics and sediment transport in selected reaches, thereby accelerating recovery processes to increase habitat diversity (Downs & Gregory, 2004). In the formulation of fisheries enhancement or rehabilitation programmes it is often the case that a suite of measures comprising different methods under the following headings (Measures 2-5) may be required to address habitat imbalances or deficiencies in a particular river reach.

Measure 2 Narrowing of channels

Outline: Alternative methods can be used to reduce the width of channels which have been excessively widened through arterial drainage works resulting in a loss of habitat diversity.

Based on installation of deflector structures to form 2-stage channel which creates meanders within the straightened channel and does not affect conveyance. Alternative structures such as low weirs and aquatic ledges can be deployed to achieve localised narrowing of channel.

Benefits:

- Restoration of natural channel basewidth
- Reduction of low water channel capacity
- Increase in water depth and velocity to create scouring
- Introduction of channel sinuosity
- Restoration of habitat diversity

Application: Streams excessively widened due to drainage works

Feasibility: Not suitable in low gradient stretches. Depends on machine access to site and ease of transporting materials

Effectiveness: Very effective in re-introduction of instream habitat diversity; also effective in longer term benefits to overall aquatic and riparian communities.

Specification/Description: O'Grady (2006); Summers et al (1996); RRC Manual (2002); Ward et al (1994)

Measure 3 Re-construction of pools

Outline: Pools are a natural feature of rivers and provide essential habitat for salmonids. They are produced and maintained by the scouring effect of the stream but are often missing from drained channels due to over-widening, straightening and lack of mobile substrates.

Benefits: Addresses imbalance in salmonid habitat features

- Provides deep water habitat for age-1 and older juvenile salmonids
- Provides deep water habitat for adult salmonids
- Pools act as refuge for all stages during drought conditions

<table>
<tr><th>Alternative methods</th><th colspan="2">Application</th></tr>
<tr><td>Excavation of lateral scour pools</td><td colspan="2">Meandering reaches with hard substrate</td></tr>
<tr><td>Bank stabilisation (see measure 14)</td><td colspan="2">Meandering reaches with mobile substrate</td></tr>
<tr><td>Stone weirs</td><td rowspan="3">Smaller channels < 4m</td><td rowspan="4">Straight reaches</td></tr>
<tr><td>Timber weirs</td></tr>
<tr><td>Channel constrictors</td></tr>
<tr><td>Vortex weirs</td><td>Larger channels ≥ 3.5m</td></tr>
</table>

- Gravels tend to deposit immediately downstream to form spawning areas

Application: To re-create pools a range of different methods can be applied according to longitudinal channel profile and substrate characteristics.

Feasibility: Not suitable in low gradient stretches. Depends on machine access to site and ease of transporting materials

Drainage implications – can cause problems through raised water levels and increased frictional drag if specification or location not suitable.

Effectiveness: Very effective in increasing habitat diversity and salmonid standing crop

Specification/Description: O'Grady (2006); Summers et al (1996); RRC Manual (2002)

Measure 4 Substrate enhancement

Drained sections of rivers can be lacking in the coarse substrates of varying sizes which are an essential feature of different stages of the salmonid life cycle. Different measures can be adopted to address specific deficiencies e.g. rubble mats, spawning gravels, boulder placement, breaking sheet rock.

Measure 4.1 Rubble mats

Outline: Raising of the riverbed by installing rubble mats to create riffle areas introduces complexity into an otherwise uniform substrate and increases the productivity of macroinvertebrates and fish.

Benefits:

- Localised reduction in channel capacity at rubble mat increases water velocities during low flow conditions

- Flow characteristics in combination with new substrate creates favourable habitat for invertebrates and juvenile salmonids
- Increased water velocities concentrated in centre channel scours pool or maintains excavated pool
- Extra pools increase holding area for adult fish
- Can also result in accumulation of gravels to form spawning area

Application: Shallow locations in uniform glides lacking in instream cover.
Lowland streams over-deepened by drainage works.

Feasibility: Depends on machine access to site and ease of transporting materials. Drainage implications – can cause problems through raised water levels and increased frictional drag if specification or location not suitable.

Effectiveness: Effective in increasing habitat diversity, invertebrate biomass and fish carrying capacity

Specification/Description: O'Grady (2006); Summers et al (1996); RRC Manual (2002); Hey (1994)

Measure 4.2 Spawning beds

Outline: Gravel beds are essential for salmonid spawning and must be located in areas with the correct hydraulic conditions to draw sufficient water through gravel to ensure an oxygen supply to deposited ova.

Natural gravels abundant: When sufficient quantities of mobile gravel are present, spawning beds can be created through natural accumulation of gravel at the tail of weir pools. At higher gradients, gravel retaining structures will accumulate gravel.

Natural gravels lacking: In the absence of natural gravel deposits, spawning beds can be developed using different methods:

- rubble mat construction using gravel materials rather than crushed rock or cobble
- addition of gravel in meandering channels at naturally depositing locations e.g. upstream and downstream of lateral scour pools
- addition of gravel in straightened channels at the tail of weir pools
- excavation of coarse substrate and replacement with gravel

Benefits:

- Creation of new spawning area for salmonids
- Flow characteristics in combination with new substrate can enhance habitat for invertebrates and juvenile salmonids

Application: Shallow locations in uniform glides

Lowland streams over-deepened by drainage works

Feasibility: Depends on machine access to site and ease of transporting materials

Effectiveness: Can be very effective by increasing spawning range, fry distribution and fish carrying capacity. Effectiveness can be limited by siltation or gravel wash-out during periods of high flow.

Specification/Description: O'Grady (2006); Summers et al (1996); Ward et al (1994); Nielsen (1996); SEPA (2002).

Measure 4.3 Boulder placement

Outline: Boulders of different sizes are a natural feature in river channels creating cover and refuge areas for both juvenile and adult salmonids

Benefits:

- Creation of favourable hydraulic conditions for fish to hold station with minimum effort.
- Reduction of visual contact between fish, and thereby increase the number of potential territories
- Increased productivity of invertebrates through creation of additional habitat
- Dissipate energy of stream during high flows which helps to limit bank erosion
- Help to scour out silt deposits in channel

Application: Any stream lacking in instream cover for fish. Not suitable in low energy stream with high sediment load.

Feasibility: Depends on machine access to site and ease of transporting materials.

Drainage implications – can cause increased channel roughness and frictional drag with potential reduction in channel capacity and a degree of impoundment upstream.

Effectiveness: Very effective in increasing invertebrate and fish carrying capacity. Particularly effective areas of little macrophyte growth

Specification/Description: O'Grady (2006); Summers et al (1996); SEPA (2002).

4.2.3 SUB-PRESSURE: Channel alteration
- straightening, deepening, widening of channel (b)

IMPACT: Loss or impairment of riparian zone

4.2.4 SPECIFIC MEASURES:

<u>Measure 5 Fencing programmes to exclude livestock</u>

Outline: Fencing can be erected to exclude livestock from the bank area and the channel to prevent grazing of riparian and instream vegetation, and trampling of banks which may have led to over-widening of the stream. Grazing by livestock prevents the establishment of a balanced riparian zone in which a dense growth of vegetation promotes stabilisation of banks and prevents erosion.

This is an important measure along any river where livestock grazing is the dominant land use, but is particularly applicable in areas where riparian zone is impaired and where bank stabilisation or other instream enhancement measures have been applied.

Benefits:

- Bank stabilisation and reduction of erosion rates
- Protection of newly stabilised banks
- Recovery of riparian zone
- Reduced input of fine sediments
- Shading of channel
- Narrowing of channel through encroachment of vegetation

Application: All rivers and streams where livestock grazing is the dominant land use.
In association with instream mitigation measures.
In association with bankside planting.
As a sole measure.

Feasibility: Dependent on landowner agreement.
Can be damaged by overbank floods.
Potential maintenance requirement.
Can be regarded as aesthetically unattractive.

Effectiveness: Often very effective as sole measure and can be critical factor in ensuring success of bank stabilisation works and instream enhancement measures.

Specification/Description: O'Grady (2006); Summers et al (1996); Ward et al (1994)

4.2.5 SUB-PRESSURE: Flood walls and embankments

IMPACT: Reduced floodplain area/ loss of riparian zone and marginal habitats/ reduced connectivity with floodplain/ entrapment of sediments.

4.2.6 SPECIFIC MEASURES:

Measure 6 Removal or re-location of flood banks

Outline: The overflowing of rivers onto the surrounding floodplain is a natural process which has been curtailed by the construction of embankments, usually immediately adjacent to the river, effectively producing a deeply incised channel with increased capacity for flood containment and alteration of related fluvial processes e.g. flow velocity, sediment transport.

This also results in a loss of wildlife habitats, impacting particularly on plant and animal species which depend on periodic inundation, waterlogging and slow drying of floodplains. Concrete flood-walls rising directly from the channel in urban areas have entirely eliminated the riparian zone from rivers.

Removal of floodbanks from riverbank to reinstate floodplain increases connectivity with floodplain, reduces sediment load in river and improves flood protection in downstream areas. Alternatively, re-location of floodbanks set back from river creates a semi-natural floodplain gives some level of benefit in these areas.

Benefits:

- increases connectivity with floodplain
- reduces sediment load in river
- improves flood protection in downstream areas
- reduces peak flow velocities and erosive power of river
- restores riparian and floodplain habitats
- relatively low cost and maintenance

Application: Potentially any channel enclosed by floodbanks, but particularly in areas upstream of urban flooding problems.

Feasibility: Heavily dependent on landowner support, and would potentially require multiple participants for implementation over significant floodplain area. Therefore not a practical measure in Ireland. Possibly some scope on small scale in short stretches on smaller tributaries, but benefits proportionately reduced.

Effectiveness: Likely to be most effective to overall catchment sediment loads and flood management. Instream measures likely to be more effective in immediate area where benefits more tangible for riparian and floodplain habitats.

Specification/Description: RRC (2002); WWF (2001).

4.2.7 SUB-PRESSURE: Drainage maintenance works

IMPACT: Loss of morphological and ecological diversity
Disturbance of riverbed and banks/ mobilisation of sediments/ loss of instream and riparian vegetation.

4.2.8 SPECIFIC MEASURES:

Measure 7 Application of OPW Environmental Drainage Maintenance Guidelines

Drainage maintenance is less extreme than in the past, works now consisting mainly of the removal of silt and excessive weed growth using hydraulic excavators, while impinging trees may be completely removed or pruned to remove the lower branches. These works, by nature, result in changes to river morphology which impact on river and riparian ecology.

However OPW and CFB have developed an environmental approach to maintenance in order to minimise impacts along with a training programme for OPW maintenance staff. The approach focuses on 10 steps to *Environmentally Friendly Maintenance*:

1	Protect bank slopes	Standard procedure
2	Restrict maintenance to channel	
3	Deposit spoil on bank full	
4	Selective vegetation removal	
5	Leave sections untouched	In consultation with Foreman / Technician
6	Management of trees	
7	Manage berms to form 2-stage channel	
8	Replace boulders	
9	Loosen bed gravels	In consultation with Fisheries Advisor
10	Excavate pools	

Feasibility: This approach has been adopted throughout the 3 OPW Drainage Maintenance East Regions. These principles need to be extended to small-scale standalone schemes (Drainage Districts) carried out prior to the 1945 Act and now maintained by Local Authorities. Each step should be feasible to a greater or lesser degree in any particular stretch of river requiring maintenance works.

Measure 7.1 Protection of bankslopes

Outline: Vegetation is retained on non-working bank and scraping is minimised on working bank.

Benefits:

- minimum disturbance of riparian zone
- minimises area of exposed bank and potential sediment input
- contributes to channel recovery following maintenance

Application: Any channel where maintenance works are required.

Feasibility: Feasible in any channel where reduction in channel capacity is not due to excessive growth of vegetation on banks.

Effectiveness: Effective in preserving bankside riparian area and assisting channel recovery following maintenance.

Specification/Description: King (2001); OPW (2007); Ward et al (1994).

Measure 7.2 Restriction of maintenance to channel

Outline: Removal of instream material only and retention of marginal vegetation

Benefits:

- maintains stability of banks
- retains habitats and cover associated with marginal vegetation
- minimum disturbance of riparian zone
- minimises area of exposed bank and potential sediment input
- facilitates instream restorative works to benefit fisheries

Application: Any channel where maintenance works are required

Feasibility: Feasible in any channel where reduction in channel capacity is largely due to silt deposition and / or excessive instream growth of vegetation.

Effectiveness: Effective in preserving marginal vegetation and assisting channel recovery following maintenance.

Specification/Description: OPW (2007); Ward et al (1994).

Measure 7.3 Deposit spoil on bankfull

Outline: Excavated materials to be deposited on the bankfull area or in spoil heaps as opposed to on bankslopes.

Benefits:

- minimises potential for spoil materials to be shifted by flood events
- minimises damage to riparian vegetation
- maximises channel capacity

Application: Any channel where maintenance works are required

Feasibility: Feasible in any channel where reduction in channel capacity is largely due to silt deposition.

Effectiveness: Effective in preserving riparian zone and reducing potential for sediment transport.

Specification/Description: OPW (2007); Ward et al (1994).

Measure 7.4 Selective vegetation removal

Outline: Removal of principal vegetation hindering conveyance e.g Water celery and tall emergent vegetation contributing to sediment accumulation, *Scirpus lacustris* (Bulrush) and *Sparganium erectum* (Bur-reed). Retention of marginal grasses e.g. *Phalaris arundinacea* (Canary grass).

Benefits:

- maximises channel capacity and conveyance
- minimises damage to marginal vegetation
- retains cover for fish from marginal grasses

Application: Any channel where maintenance works are required

Feasibility: Feasible in any channel where reduction in channel capacity is largely due to excessive growth of vegetation, notably water celery and tall emergent vegetation with associated problems of silt deposition.

Effectiveness: Effective in restoring conveyance while retaining an element of cover from marginal vegetation.

Specification/Description: King (2001); OPW (2007); Ward et al (1994).

Measure 7.5 Leaving sections untouched

Outline: During maintenance works sections of channel can be left untouched in situations where the gradient and channel properties are effectively self cleaning and the channel is naturally holding its designed conveyance capacity (provided there is no other encroachment reducing conveyance capacity e.g. fallen trees, bank slippage etc). This may apply to varying lengths of channel ranging from a short section to an entire reach.

Benefits:

- minimum channel disturbance

- continued natural recovery of channel
- retention of habitat diversity
- untouched section acts as an wildlife “oasis” and will assist with recolonisation of worked reaches, especially by macroinvertebrates
- less spoil to dispose of
- cheaper than continuous dredging

Application: Any channel where maintenance works are required

Feasibility: Technical judgement required on whether section can be left untouched – this may be subjective to some degree.

Effectiveness: Very effective in minimising disturbance, facilitating natural recovery and preserving habitats

Specification/Description: King (2001); OPW (2007); Ward et al (1994).

Measure 7.6 Management of trees

Outline: 3 measures are recommended to ensure maximum retention of trees on riverbanks unless impacting on channel capacity:

- leaving trees intact if not causing any reduction in channel capacity
- removal of overhanging branches to flood level
- use of saw or secateurs for cutting, rather than excavator

Benefits: Riverbank trees provide several benefits:

- preservation of root structure assists bank stability
- shading effect provides cover for fish, limits water temperature and prevents excessive macrophyte growth
- provide food and shelter for many different animals (insects, birds, mammals)
- leaf litter falling into watercourses is a food source for aquatic invertebrates
- instream root structure provides refuge for fish and invertebrates
- cavities in banks under large tree roots are potential otter holts

Application: Any channel with bankside tree and scrub growth where maintenance works are required.

Feasibility: Some elements of this approach should be feasible in all cases, but tree removal or extensive cutting may be required to permit machine access for channel maintenance.

Effectiveness: Preservation of tree cover shown by CFB to be effective in retention of larger, older fish. Also effective in general environmental terms with regard to minimisation of impacts on riparian community.

Specification/Description: Ward et al (1994); WWF (2001); King (2001); King & Wightman (2006); OPW (2007).

Measure 7.7 Adjustment of berms to form two-stage channel

Outline: Measures designed to improve channel capacity without impacting on the beneficial effects of channel narrowing through deposition of sediments:

- removal of top of berms to low flow level
- removal of vegetation and soil from gravel berms
- replacement of sods to the berms where feasible

Benefits:

- retains narrow low flow channel to create 2-stage channel
- exposes potentially useful gravels
- sod replacement prevents exposure of bare banks with potential silt input, facilitates rapid re-growth of bank vegetation and assists bank stability.

Application: Any channel where maintenance works are required due to lateral siltation.

Feasibility: Should be feasible in all cases.

Effectiveness: Very effective in preventing instream disturbance and preserving instream morphological diversity.

Specification/Description: Ward et al (1994); King (2001); OPW (2007).

Measure 7.8 Replacement of boulders

Outline: The importance of boulders in providing fish habitats is described at 4.3 (Measure 4). In the context of drainage maintenance it is suggested that:

- boulders and other coarse substrate materials are reinstated as removed during maintenance operations
- boulders are reinstated to channel from spoil heaps
- boulders are placed below low flow level and are staggered.

Benefits: (as noted under Measure 4)

Application: Any channel in which boulders and other coarse materials are removed during maintenance; boulders can also be extracted from existing spoil heaps.

Feasibility: Sorting of boulders etc from silt deposits and spoil heaps may be time consuming.

Effectiveness: Very effective in minimising impact of maintenance and preserving habitat diversity. Use of materials from existing spoil heaps constitutes *restorative* maintenance.

Specification/Description: O'Grady (2006); Ward et al (1994); OPW (2007); Summers et al (1996); SEPA (2002).

Measure 7.9 Loosening of bed gravels

Outline: Gravel beds are important for salmonid spawning but can become compacted or inundated with silt. In limestone catchments gravel can become encrusted and inaccessible for spawning due to precipitation of calcium carbonate. Loosening or tossing of gravels is effective is such cases.

Benefits:

- reinstatement of spawning areas
- enhancement of spawning potential and carrying capacity

Application: Gravelled areas are usually by-passed during maintenance works. Inspection of gravel beds therefore required to determine feasibility.

Feasibility: Should only be carried out from 1 July to 30 September.

Effectiveness: Very effective in restoring spawning areas. An example of *restorative* maintenance in section which would not normally require maintenance.

Specification/Description: King (2001); O'Grady (2006); Summers et al (1996).

Measure 7.10 Excavation of pools

Outline: The importance of pool habitats for fish is outlined under Measure 3.

- pools should be excavated in a staggered formation along the centre and sides of the channel
- excavated materials should be placed to form adjacent riffles

Benefits: (as noted under Measure 3)

Application: Any channel undergoing maintenance, particularly if there is a lack of pool habitats.

Feasibility: Pools should only be excavated if the channel bed is of suitable coarse materials as opposed to deposits of fine material.

Effectiveness: Very effective in increasing carrying capacity of 1+ salmon and trout in small streams (< 3m basewidth). Also effective in larger channels through enhanced carrying capacity of 1+ and older trout and salmon, including adults. This is a further example of *restorative* maintenance.

Specification/Description: O'Grady (2006); Ward et al (1994); Summers et al (1996); OPW (2007)

Measure 8 Incorporation of river restoration & fisheries enhancement projects (see Measures 1-5)

Outline: This approach requires the inclusion of physical enhancement works in the drainage maintenance schedule to achieve an *enhanced drainage maintenance programme.* This principal has been adopted by OPW from 2008 for implementation on 50km of river per year. The approach is likely to require a combination of methods listed under Measures 1-5 to address habitat imbalances or deficiencies in a particular river reach.

Benefits: (as noted under Measures 1-5)

- potential to improve ecological status

Application: Could be considered in any channel requiring maintenance works.

Feasibility: Will be limited to channels of sufficient gradient (> 0.2%) and satisfactory water quality.

Effectiveness: Potentially effective in minimising impact of maintenance and addressing damage caused by original drainage scheme.

Specification/Description: (as noted under Measures 1-5)

Measure 9 Measures to facilitate natural recovery

Outline: Natural morphological recovery of a channel, towards a new equilibrium or the pre-drainage condition, is conditional on removal or cessation of the original disturbance (Swales 1989). A cessation of maintenance works or a reduction in the scope of works may therefore facilitate longer term natural recovery of the channel. This may be achieved through the incorporation of environmental considerations in the selection criteria for maintenance works as recommended at 3.7.5 (p16). The objective would be to include environmental considerations along with drainage considerations in the decision making process to determine whether maintenance works are required.

Benefits:

- natural recovery of channel diversity according to inherent hydrological and sediment transport characteristics
- no costs incurred in contrast to active intervention

Application: All drained channels subject to maintenance works

Feasibility: Feasible in areas where environmental considerations may outweigh drainage considerations. However there may be broader social and economic consequences to maintenance cessation as outfall for agricultural productivity reduces and flood risk increases in some areas. Landowners' agreements will be required and compensation may be an issue.

Effectiveness: The ability of rivers to recover ecologically is largely dependent on channel gradient and immediate subsoil characteristics. Effectiveness may be limited in low gradient, high maintenance channels with heavy accumulation of silt and associated plant proliferation.

Specification/Description:

4.2.9 SUB-PRESSURE: Hard protection – sheet piling, vertical walls

Many watercourses in urban development and parkland areas have been constrained within hard bank reinforcement structures of sheet piling, concrete or brick walls creating an un-natural channel form with no riparian zone. In some cases the channel bed is also reinforced leading to an even more extreme environment.

IMPACT: Loss of riparian zone and marginal habitats / loss of lateral connectivity / loss of sediment input. If bed reinforced, channel likely to be of uniform depth with lack of natural bed materials.

4.2.10 SPECIFIC MEASURES:

Measure 10 Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution

Outline: Dismantling of bank and bed reinforcement structures to facilitate a natural recovery process. Banks should be re-profiled allowing some variability to create a more natural channel form. Methods to facilitate assisted natural recovery may be included (see Measures 2-4) - a 2-stage channel will also increase flood storage and increase channel capacity. Re-meandering may be included if feasible (see Measure 1). Off-line ponds may enhance habitat and amenity value. Soft engineering solutions may include bank stabilisation methods (see Measure 14) or alternative bank revetment methods using live trees and shrubs e.g. willow spiling and faggoting.

Benefits:

- creation of more natural channel maintained by natural processes
- restoration of riparian zone and marginal habitats
- restoration of aquatic habitats

- allows controlled flooding of amenity and parkland areas (not appropriate in built areas)
- reduction of downstream flood pressures

Application: Surface level watercourses in urban areas, industrial estates, residential areas, amenity and parkland areas. In new greenfield or brownfield development areas it is important to avoid hard engineered confinement of watercourses, adjusting the development to make the stream its focus, rather than a hazardous obstacle which must be constrained.

Feasibility: Most feasible in amenity and parkland areas not constrained by building and/or road development. In some situations it may only be feasible to carry out single bank restoration measures.

Effectiveness: Very effective in restoring watercourse from extreme, un-natural condition lacking aquatic, marginal and riparian habitats.

Specification/Description: SEPA (2000); RRC Manual (2002); Ward et al (1994)

4.2.11 SUB-PRESSURE: Culverts

Culverts are encased underground watercourses which can range from narrow pipes through to large, square-sided channels. They have generally been constructed to facilitate ground level development (urban, industrial, residential), to manage flood flows where a natural channel was considered inadequate, and to minimise safety issues. However, culverts provide a highly un-natural environment of little ecological value.

IMPACT: Loss of morphological diversity and habitat.
Reduced light input.
Potentially increased flood risk both upstream and downstream.
Disruption of longitudinal connectivity with implications for migration of fish and other species (See Section 4.5: Barriers to Migration)

4.2.12 SPECIFIC MEASURES:

<u>Measure 11 Re-opening of existing culverts (de-culverting or daylighting)</u>

Outline: The re-opening of culverts provides an opportunity to restore a more natural channel. For large culverts with no adjacent development, the aim should be to return the watercourse to a more naturally functioning form. For channel/box culverts with adjacent development, the culvert should be opened and the bed returned to a natural state. Culvert removal, backfilling and reshaping of the channel may be significantly more expensive than digging a new channel and closing of the redundant culvert section. Procedures are similar to removal of hard bank reinforcement (see Measure 10) and may incorporate re-meandering of the channel (Measure 1) and methods to assist natural recovery (Measures 2-4). Can be carried out over a selected reach of the culvert, retaining culverted sections at each end which may not be feasible to restore – in this situation it is good practice to incorporate sediment traps at each end of the restored section where it emerges from and re-enters the culvert.

Benefits:

- creation of more natural channel maintained by natural processes
- restoration of aquatic, riparian and marginal habitats
- restoration of aquatic habitats
- allows controlled flooding of amenity and parkland areas (not appropriate in built areas)
- reduction of upstream and downstream flood pressures

Application: In theory all culverted watercourses should be considered for re-opening but in practice the opportunities will be limited to parkland areas, areas with no adjacent development and urban regeneration areas. The removal of a culvert must therefore be physically possible within the context of the local physical and built landscape, and should have sufficient scope for restoration of habitats and enhancement of the local environment. Flood risk issues associated with culverts may become more pronounced with more extreme rainfall events due to climate change, and de-culverting may become an effective adaptation measure. Culverting should be avoided in new greenfield or brownfield development sites, adjusting developments to maximise the ecological and amenity potential of watercourses.

Feasibility: Once covered, the land above culverted watercourses may become heavily developed to the extent that de-culverting is not a realistic option. Therefore de-culverting is probably most feasible in parkland and urban regeneration areas. De-culverting may only be possible, both practically and financially, over a selected reach of the culvert, retaining culverted sections at each end which may not be feasible to restore.

Effectiveness: Very effective in restoring watercourse from extreme, un-natural condition lacking aquatic, marginal and riparian habitats.

Specification/Description: SEPA (2000); RRC Manual (2002); Anon (1998)

4.3 PRESSURE: IMPOUNDMENTS & REGULATION

Numerous weirs and dams were constructed on Ireland's rivers for water power to mills and laterally for hydro-power. In low gradient areas these structures can impound significant lengths of channel which are very unproductive in ecological terms relative to shallow riffle and glide reaches. The abstraction of large volumes of water at dams and weirs relative to the main flow of the river can also have significant morphological and ecological effects on the channel in the immediate downstream reach until the point at which the diverted water is returned.

Many of these weirs and dams have been dismantled during arterial drainage schemes but a significant number remain intact although relatively few remain operational.

(These structures can also present a major obstacle to upstream migration of salmonids although most have now been modified to incorporate a fish pass. Refer to Barriers to Migration: Measures 21-23).

4.3.1 SUB-PRESSURE: Dams & weirs (a)

IMPACT: Loss of morphological and ecological diversity
Reduction in productivity
Accumulation of sediment upstream
Loss of sediment input downstream

4.3.2 SPECIFIC MEASURES:

Measure 12 Removal of structure and de-silting of impounded reach

Outline: Dismantling of weirs no longer in operation and de-silting of the impounded area upstream to restore a more "natural" river morphology and habitats.

Benefits: Removal of impounding structures will:

- Create new shallow areas and thereby improve river morphology
- Reversion to more natural river morphology and ecology
- Increase production in the newly-created shallow areas
- Restoration of longitudinal continuity

Application: Any structure that creates a significant impounded area in which water depth is largely in excess of 1.5m.

Feasibility: May be limited due to ownership of water rights or industrial heritage value of structure.

Effectiveness: Very effective in raising productivity. (Also effective in removing barriers to migration – see Measures 21-23). However this measure will lead to a loss of the range of habitats and species dependent on the impounding structure and may cause an increase or decrease overall biodiversity. Water related activities such as angling for coarse fish may also be affected as the waterway reverts to salmonid characteristics.

Specification/Description: O'Grady (2006); Summers et al (1994).

4.3.4 SUB-PRESSURE: Dams & weirs (b)

IMPACT: Inadequate residual flow downstream
Loss of morphological and ecological diversity
Intermittent disruption of aquatic community

4.3.5 SPECIFIC MEASURES:

Measure 13 Adoption of operational protocols

Outline: This measure refers to the practices adopted at weirs with respect to the abstraction of water for small hydro electric schemes or other industrial purposes. It is particularly relevant in the case of low head hydro schemes in which a large volume of water is normally diverted from the main channel relative to the total flow in the river. In addition, it can be some distance before the diverted water is returned to the river due to the low river gradient at some of these locations.

If an excessive volume of water is diverted from the river in this way, relative to its overall flow, the result can be a considerable length of main channel with a significantly depleted or perhaps zero flow. Clearly this can alter river morphology through a basic lack of water which can seriously impact on the productivity of flora, invertebrates and fish. Additional potential impacts are addressed under Barriers to Migration (Measure 23).

The solution to this pressure is to ensure that the regulatory conditions applied to small hydro schemes and other abstraction operations are sufficient to allow for an adequate residual flow in the main channel at all times. Current legislation does not deal with water diversion and compensation flows, although some planning authorities stipulate that hydro station throughput should never exceed 50% of the total available flow. However this assumes that the residual 50% is an adequate allocation for the natural channel, and there is usually an additional requirement that the residual flow should not fall below a specified limit.

It has recently been recommended that a minimum standard at small hydro schemes is a compensation flow provision of 12.5% of the long term mean flow. In situations where there is spawning and nursery potential and where there is also fish movement through the stretch the compensation flow should be 12.5% of the long term mean flow, or 50% of the available flow upstream of the intake point, whichever is the greater. (There are additional recommendations with regard to fish migration – see Measure 23).

Benefits:

- Maximisation of wetted area of riverbed
- Restoration / maintenance of morphological diversity
- Restoration / maintenance of longitudinal continuity

Application: All weirs and dams at which significant volumes of water are diverted from the main channel. Conditions for operation should be applied by planning and regulatory authorities.

Feasibility: Difficult to apply to existing situations where excessive abstractions have been taking place for some time. Difficult for regulatory authorities to ensure that specified conditions are adhered to. A satisfactory means of measuring and recording should be incorporated to verify how much water a hydropower scheme abstracts.

Effectiveness: Will make significant improvements in situations where excessive abstractions have being taking place, although some minor impacts likely to remain.

Specification/Description: Anon (2007b); Anon (2000c).

4.4 PRESSURE: INTENSIVE LAND USE

Many changes took place with regard to land use practices during the 20th century in the areas of agriculture, industry and urban development, in all cases resulting in an intensification of land use. These changes have resulted in both direct and indirect impacts on river morphology.

4.4.1 SUB-PRESSURE: Overgrazing & bank trampling

During the last 30 years overgrazing by sheep flocks became a serious problem in the west of Ireland resulting in increased run-off rates with severe bank erosion and sediment input to river channels. The problem of over-stocking with sheep has been addressed but extensive damage to river channels remains. Bank trampling by cattle has also led to excessive bank erosion in many channels.

IMPACT: Loss of riparian zone
Excessive bank erosion
Sediment deposition in watercourses
Over-widening of channel / braided channels

4.4.2 SPECIFIC MEASURES:

In contrast to *Assisted natural recovery* (Measures 2-4), non-structural measures can be implemented to allow the river to recover naturally, a process which has been described as *Benign neglect* (Downs & Gregory, 2004). This involves catchment-level water and/or land management policies to restore natural run-off and sediment regimes. This can be achieved by scaling back or regulation of intensive land use (Measures 14-20), or by allowing agricultural land to fallow back to its natural vegetation type, allowing run-off and sediment input to the channel to revert over time to levels closer to the pre-disturbance situation (Downs & Gregory, 2004). These policies are only practicable in catchments of low population density.

Measure 14 Stabilisation of river banks

Outline: Excessively eroded banks and those damaged by trampling can be repaired and stabilised using various combinations of logs, rocks and conifer tree tops to form bank revetments:

- Log / Christmas tree
- Log / rock
- Root wads
- Standard rip-rap
- Rock shelves

Soft revetment techniques such as the log/xmas tree revetment are the best option as they permit the bank to rebuild itself, while erosion is not eliminated but reduced to natural level. Root wads or rock only *hard* solutions are the only option in high energy channels.

Bank revetment measures should always be accompanied by a fencing programme in reaches where livestock are present (see Measure 5). Planting with willows or other native deciduous species should also be carried out.

Benefits:

- Reduction of erosion to a natural level
- Reduction in sediment input
- Narrowing of channel
- Stabilisation of banks and recovery of instream and riparian habitats

Application: Any channel reaches in which excessive erosion is occurring. Technique will depend on gradient (high/low energy), natural bank and bed materials, and level of suspended solids during flood conditions.

Feasibility: Depends on hydraulic machine access to site and ease of transporting materials although machine may not be required for soft techniques on some smaller streams.

Effectiveness: All methods effective in restoring stability but success dependant on fencing out of livestock. Disadvantage of hard techniques is that erosion of bankside gravels to replenish spawning beds is eliminated.

Specification/Description: O'Grady (2006); WWF (2001); Summers et al (1996).

Measure 15 Application of REPS special measures

Outline: The Rural Environment Protection Scheme (REPS) is designed to reward farmers for carrying out their farming activities in an environmentally friendly manner. Various scales of payment are available to farmers who adopt recommended farming practices and production methods to minimise environmental impacts in line with the protection of wildlife habitats and endangered species of flora and fauna. The Scheme includes a series of measures, three of which reduce the impacts of overgrazing and bank trampling:

Measure 15.1 REPS Measure 2: Grassland and Soil Management Plan

The objective of this measure is to promote a sustainable grassland management plan that protects habitats, minimises poaching, overgrazing and soil erosion. There are several requirements including the location of supplementary feeding points at least 30 metres from any watercourse or waterbody.

<u>Measure 15.2 REPS Measure 3: Protect and Maintain Watercourses, Waterbodies and Wells</u>

The objective of this measure is to avoid nutrient enrichment of waterbodies by creating a buffer strip to intercept the overland flow of nutrients and thus maintain or improve water quality. This enables natural streamside vegetation to develop and improve biodiversity by attracting a wide range of flora and fauna.

This measure specifies the fencing of watercourses/waterbodies to prevent access by bovines to within 1.5 metres of watercourses with fences at least 1.5 metres from the top of the bank of the watercourse. Where it is not feasible to provide a piped water supply for animals, access to drinking points may be provided. Access for animals and machinery across watercourses must, as far as possible, be by way of suitable culverts.

In relation to watercourse maintenance this measure also specifies the method, timing and frequency of work that should be carried out.

Further options under this measure:

Option 3A - Increase watercourse margin.

Fencing to exclude livestock as above with 2.5m limit.

Option 3B - Exclude all bovine access to watercourses.

No livestock access to drinking points or watercourse crossings.

Option 3C – Use of planted buffer zones.

Planting of buffer zones at least 5 metres wide along watercourses with willow or other suitable species, with buffer strip not closer than 3m from the top of the bank of the watercourse.

<u>Measure 15.3 REPS Supplementary Measure 4: Riparian Zones</u>

This measure is aimed specifically at rivers designated as containing either salmonid, freshwater crayfish or pearl mussel species. The creation of a stock-proof, linear buffer strip or riparian zone of 10-50m is required.

Benefits:

- Reduction of overgrazing and bank trampling impacts on watercourses
- Exclusion or restricted access for livestock to watercourses
- Development of buffer strips and riparian zone with range of new habitats
- Increase in morphological and ecological diversity

Application: Applies to farmers with a minimum of 3 hectares owned or leased (excluding commonage and grazing rights) and a minimum stocking density of 0.15 livestock units per hectare of forage. Participants must agree to join REPS for

5 years and must prepare a farm plan outlining how they propose to manage their farms to meet the requirements of the scheme.

Feasibility: Only feasible as a significant mitigation measure if a significant watercourse(s) passes through the participants' land.

Effectiveness: Potentially very effective through good rate of uptake and correct adherence to requirements of relevant measures.

Specification/Description: Anon (2007a).

Measure 16 Fencing programmes to exclude livestock

(See Measure 5)

4.4.3 SUB-PRESSURE: Forestry operations

Ireland has the lowest area of forest cover of all European countries at just over 10%, but Government policy is to increase this to 17% by 2030. Initially, the State carried out most tree planting but since 1991 more planting has been carried out by the private sector, mostly farmers, with the assistance of EU grant aid. Most of the early development involved coniferous planting in upland mountain areas with a more recent move into poor quality low-lying agricultural land.

IMPACT: Several negative impacts relating to river morphology can arise from forestry practices if not carried out according to modern industrial standards:

- Increased run-off rate through forestry drainage systems
- High risk of soil erosion and sediment input from steep areas with particular soil types (e.g. peat, sandstone-derived soils)
- Planting too close to a watercourse can cause excessive shading problems potentially leading to eventual tunnelling

(Additional impacts relate to chemical effects – not relevant to river morphology).

4.4.4 SPECIFIC MEASURES:

Measure 17 Application of best practice guidelines

Outline: The *Forestry and Water Quality Guidelines* were developed by the Forest Service in consultation with a wide range of relevant parties to assemble a series of practical measures based on the principles of Sustainable Forest Management. The leading measures relating to impacts on river morphology fall under 3 headings:

Measure 17.1 Buffer zones

A buffer zone of at least 10m on both sides of watercourses should be maintained free from ground preparation and any coniferous planting – on steeper sloping ground a wider buffer zone is required. Natural riparian vegetation can develop in these buffer strips supplemented by planting of mixed deciduous species.

Measure 17.2 Ground preparation and drainage

This aspect requires careful planning to minimise the risk of fine sediments in water draining the site does not enter watercourses. Collector drains should be excavated at an acute angle to the contour to minimise flow velocities, and main drains should lead to sediment traps located outside the buffer zone. Drainage channels should taper out before the buffer zone to allow for natural percolation and filtration of drainage water through ground vegetation and soils within the zone. There should be no ground preparation with buffer zones.

Measure 17.3 Roads and watercourse crossings

Roads should be located at least 50m from watercourses and should follow natural contours, while drainage from roads should be routed to sediment traps. Where watercourse crossings are required, bridges or culverts should be installed rather than crossing by fords. Where culverts are used they should be embedded in the riverbed to provide unrestricted passage for fish.

Benefits: Adoption of these principals ensures that there is minimum risk of sediment input to watercourses. The development of vegetated buffer zones has a number of particular benefits:

- Avoidance of excessive shading
- Provides intermittent cover and dappled shade
- Stabilisation of banks
- Source of leaf litter input as food source for aquatic invertebrates
- Development of riparian habitats

Application: The *Forestry and Water Quality Guidelines* apply to all grant-aided projects and to all activities associated with a Felling Licence.

Feasibility: In practical terms it may not always be possible to adhere completely to all recommended practices e.g. slope of drains, location of roads etc.

Effectiveness: Generally effective in minimisation of sediment inputs.

Specification/Description: Anon (2000a); O'Grady (2006).

4.4.5 SUB-PRESSURE: Peat extraction

Peat is harvested from Irish bogs on an industrial scale for the generation of electricity and the production of horticultural products and commercial fuel. The initial drainage of the bog and subsequent peat extraction activities result in an increase in the amount of water emanating from sites as both baseflow and storm water, potentially leading to large quantities of peat silt being discharged to the aquatic environment. The potential for run-off of peat silt is greater during extreme rainfall events.

IMPACT: The run-off of peat silt from these operations can seriously impact on receiving rivers through:

- Settlement on key substrates e.g. salmonid spawning and nursery areas
- Formation of secondary banks and islands which vegetate, stabilise and may alter stream morphology and hydrology
- Prevention of erosion of gravel and cobble materials from banks back into channel
- Elimination of flora and fauna on lake beds

Major settlement of silt is more likely in low gradient reaches of rivers is this material consists of very fine particles. This has been a particular problem in some drained channels and has impeded the process of natural recovery.

4.4.6 SPECIFIC MEASURES:

Measure 18 Operation and maintenance of silt traps

Outline: The amounts of peat silt discharged from peat workings can be significantly reduced through the operation of silt traps or settlement lagoons, provided they are adequately sized so as to allow sufficient time for settlement. Regular maintenance is also fundamental to ensuring that these facilities are operated efficiently.

Benefits:

- Control on levels of peat silt reaching watercourses
- Potential improvements in fish and invertebrate habitats if discharges are eliminated or reduced

Application: Settlement lagoon systems require a licence to discharge under either the Local Government (Water Pollution) Acts 1997 & 1990 or the Environmental Protection Agency Act 1992; larger operations also require an IPPC licence.

Feasibility: Legal requirement.

Effectiveness: Settlement lagoon systems are effective in reducing silt run-off if correctly sized and regularly maintained. However the state company Bord na Mona, is exempt from prosecution, and regulation would be assisted if the Turf Development Act 1945 was amended to allow prosecutions by other agencies under the Local Government (Water Pollution) Acts 1977 and 1990.

Specification/Description: O'Grady (2006); Fitzsimons & Igoe (2004).

<u>Measure 19 De-silting of affected reaches</u>

Outline: Peat silt deposits have been removed from drainage scheme channels by OPW during maintenance works. Techniques for relieving silt deposition in lake habitats have not been developed.

Benefits:

- Restoration of normal channel basewidth
- Development of morphological diversity

Application: Channels in which morphology and hydrology are adversely affected by peat siltation. Potentially more applicable to low gradient cyprinid reaches rather than salmonid reaches.

Feasibility: Only feasible when sources of peat silt input have been brought under control.

Effectiveness: Should be effective provided silt inputs have been stopped and EDM guidelines are applied in maintenance works.

Specification/Description: (As noted under Measure 7 - Application of Drainage Maintenance Guidelines)

4.4.7 SUB-PRESSURE: Hard surface run-off

As land is developed, natural drainage patterns are disrupted. Rain falling on hard surfaces in developed areas such as town centres, roads, car parks, residential areas, and industrial and commercial sites, rapidly reaches drainage systems leading to receiving watercourses. Run-off in this manner can also be easily contaminated with a range of substances including sediment deposits. Drainage of surface areas in this way also leads to a sudden rise to flood flows followed by a rapid reduction in flow when the storm event is over.

IMPACT: Run-off of silt and deposition in watercourses.
Increased peak flows.
Increased erosion of riverbanks and bed.
Damage to aquatic habitats.

4.4.8 SPECIFIC MEASURES:

Measure 20 Incorporation of SuDS processes

Outline: Sustainable Drainage Systems (SuDS) have been developed as a group of solutions to the problem of surface run-off, and are based on a series of processes which may operate on their own or in tandem:

Source control techniques

Designed to counter increased discharge from developed sites, as close to the source as possible, and to minimise the amount of water discharging directly to a river e.g. porous pavements, infiltration trenches, infiltration basins.

Permeable conveyance systems

These move run-off water slowly towards a receiving watercourse, allowing storage, filtration and some loss of run-off water through evaporation and infiltration before discharge e.g. filter drains, grass swales.

Passive treatment systems

These systems use natural processes to remove and break down pollutants from surface water run-off e.g. filter strips, detention basins, retention ponds, wetlands.

Benefits:

- Reduced run-off of silt and deposition in watercourses
- Restoration of aquatic habitats
- Reduced peak storm flows
- Reduced erosion of banks and riverbed.

- Creation of wetland habitats

Application: New development associated with town centres, roads, car parks, residential areas, and industrial and commercial sites should maximise the use of SuDS. Also potential for use of SuDS to replace existing conventional drainage systems from hard surfaces when maintenance is required.

Feasibility: Should be feasible in all new developments as costs likely to be lower due to reduced requirement for pipes, drains and manholes.

Effectiveness: Effective in ameliorating the impacts of new development, but would need to be implemented widely to replace existing drainage systems if current impacts are to be reduced.

Specification/Description: Irish SuDS (web source); Anon (2001); Anon (2002).

4.5 PRESSURE: BARRIERS TO MIGRATION

Migration in this instance refers to the migration of all fish and aquatic invertebrate species, and barriers to migration can be either man-made structures or naturally occurring features. Man-made barriers to migration include structures such as dams and weirs constructed in rivers for water power to mills or for hydroelectric generation, while bridge aprons can also seriously impede migration. Natural barriers to migration occur in the form of impassable waterfalls and rock shelves, but such features may have intrinsic landscape and ecological value and may isolate genetically rare populations upstream. The removal of natural barriers is therefore probably inappropriate for consideration in the context of raising ecological status.

4.5.1 SUB-PRESSURE: Dams, weirs, bridge aprons & culverts

Major hydro schemes and reservoir dams

The construction of major state hydro schemes on 5 catchments has resulted in serious problems with regard to fish migrations which are well documented. Similarly, a small number of catchments have been dammed to create reservoirs for water supply. Clearly in both situations these physical alterations have been required for the development of important water uses and will continue to function in this capacity. These alterations have resulted in designation as *Heavily Modified Water Bodies* under the WFD.

Industrial weirs & dams

Many weirs and dams were constructed on rivers for supply of water power to milling operations or for small hydro schemes – some small hydro schemes feature impounding structures on upland lakes. Most man-made structures were removed during arterial drainage schemes but a number of weirs remain, some of which are operational, usually for hydroelectric generation, while the remainder are generally obsolete.

Bridge aprons & culverts

Bridge aprons can impede fish movements by spreading the water flow over a wide area so that there is insufficient depth for fish to swim over the structure, while in some cases there is an insurmountable vertical drop at the downstream edge of the apron. Similarly culverts can be impassable due to insufficient water depth, angle of flow and/or excessive water velocity.

IMPACT: Lack of continuity
Obstruction to migration of fish and invertebrates

4.5.2 SPECIFIC MEASURES:

Measure 21 Removal of structures

Outline: The preferred option in the case of a barrier to migration is to remove the structure completely although this may not always be possible nor feasible e.g. in the case of major hydro scheme and reservoir dams. It is envisaged that that measure will apply principally to weirs no longer in operation.

Benefits: Removal of man-made structures will:

- Restore continuity to channel
- Facilitate free movement of fish and invertebrates

(May also improve ecological status by removing impounded area to shallow productive area – see Measure 10)

Application: Any man-made structure that prevents free movement of fish and invertebrates in both upstream and downstream directions. Many weirs have existing fish passes to accommodate the movements of salmonids but these may not be effective for other species such as eels, cyprinids, lamprey or aquatic invertebrates. In such cases, if the weir is no longer in operation, complete removal of the structure may be a more viable option than modification or construction of a new fish pass to accommodate other species

Feasibility: May be limited due to ownership of water rights or industrial heritage value of structure. Dismantling of large weirs may also be prohibitively expensive.

Effectiveness: The simplest and best solution to addressing structural barriers to migration. (Also very effective in raising productivity – see Measure 10).

Specification/Description: O'Grady (2006); Summers et al (1994).

Measure 22 Structural modification - construction of fish passes, rock ramps etc

This section outlines the measures applicable in situations where barriers require structural modification or fish pass construction/modification to address the noted impacts.

Measure 22.1 Close-to-nature fish passes

Outline: Includes:

- Bottom ramps and slopes
- Fish ramps
- By-pass channels.

These structures imitate as closely as possible, natural river rapids or streams with steep gradients. In this sense they should facilitate free passage of all fish and aquatic invertebrate species. Ramp structures are in-channel solution while by-pass channels require an off-channel route.

Benefits: This type of solution is regarded as the best way to restore fish passage in situations where the barrier cannot be completely removed.

- Imitates as closely as possible, natural river rapids or streams with steep gradients
- Facilitates free passage of all fish and aquatic invertebrate species
- Fully restores longitudinal connectivity
- Creates new riffle-type habitats

Application: Can be at sites at which the barrier is not excessively high and the downstream channel is of low enough gradient to accommodate a low-incline ramp within a reasonable distance of the barrier.

Feasibility: As above. By-pass structures are an off-channel solution and therefore require additional land-take which may not be available.

Effectiveness: More effective than technical passes in meeting biological requirements with regard to longitudinal connectivity.

Specification/Description: FAO/DVWK (2002)

Measure 22.2 Technical fish passes

Outline: Includes:

- Pool passes
- Vertical slot passes
- Denil passes
- Overspill & notch passes
- Diagonal baulks
- Eel ladders
- Fish locks
- Fish lifts

This type of fish pass has been the traditional solution in Ireland to facilitating fish passage at barriers which constitute a significant obstacle to upstream salmonid migration.

Benefits: Technical fish passes are a good solution at barriers where space may be limited but tend to require more frequent maintenance. Some are particularly suited to very high barriers such as hydro dams e.g. fish lifts and fish locks.

- Generally suited to the upstream migration of salmonids and therefore highly applicable in Ireland
- Proven technology

Application: Some types can be suitable for the passage of invertebrates (pool passes, vertical slot passes), while others are impassable to invertebrates as a bottom substrate cannot be incorporated (Denil passes, eel ladders). Fish locks and fish lifts tend to be used to overcome high barriers (e.g. hydro dams) where space is limited, but are unlikely to facilitate the movement of invertebrates.

Feasibility: Costs may be a limiting factor.

Effectiveness: Pool passes and Denil passes widely used and effective, but require frequent maintenance and may not operate effectively under varying headwater conditions. Fish lifts are used with mixed results at hydro dams, and are expensive to install and maintain

Specification/Description: FAO/DVWK (2002); Beach (1984); O'Neill & Connor (2003).

Measure 22.3 Structural alterations to aid fish passage

Outline: In some situations other than weirs and dams structural alterations may be required to facilitate fish passage e.g.

Bridge aprons

- Construction of low weirs to back up the water level over the apron, or reconstruction of bridge apron into V-shaped channel to concentrate flow towards centre.

Culverts

- Deepening the water depth through a culvert and slowing the flow is similarly achieved by installing a weir downstream of the outlet, to back up water through the culvert.
- Alternative approach is to install a system of baffles to break up the flow with local lowering of velocity and increase in water depth. Can also be achieved through installing devices to anchor rocks thereby increasing bed roughness.

Benefits:

- Suitable for strong swimming fish species
- Increases distribution of fish and spawning range
- Can create access to significant areas of catchment

Application: Bridge aprons and culverts acting as a barrier to migration

Feasibility: Some culverts may be too long or set at too steep an angle for measures to be effective. Physical access to culverts for structural works may be difficult.

Effectiveness: Effective in facilitating passage of strong swimming fish species. Simple amendments to problem bridge aprons on significant channels can be very effective. Probably ineffective for invertebrate species.

Specification/Description: Anon (1998); Anon (2000b).

Measure 23 Adoption of operational protocols

Outline: There are many examples of excessive abstraction which render fish passes, weirs or even sections of rivers, impassable and therefore create barriers to migration.

This is particularly relevant in the case of low head hydro schemes in which a large volume of water is normally diverted from the main channel relative to total flow in the river (see Measure 13). Apart from creating a barrier in the main channel, this situation also results in downstream migrant fish being drawn towards the intake, possibly sustaining damage or mortality at intake screens or at the turbine. Similarly, upstream migrants can be attracted towards the greater flow emanating from the tailrace, where they may be damaged at screens or become trapped in the tailrace.

This measure is aimed at the application of specific standards to small hydro and similar abstracting operations, to ensure that they function within pre-determined limits which will allow for the satisfactory function of fish passes and similar installations to facilitate the upstream and downstream migrations of fish species.

It has recently been recommended that, as a minimum standard, small hydro schemes should provide a compensation flow provision of 12.5% of the long term mean flow. In situations where there is spawning and nursery potential and where there is also fish movement through the stretch the compensation flow should be 12.5% of the long term mean flow, or 50% of the available flow upstream of the intake point, whichever is the greater. In some situations it has also been suggested that, to facilitate fish passage, an adequate number of artificial freshets (short term simulated floods) to allow upstream movement of fish, should be stipulated as part of the operating conditions at the appropriate times required.

Benefits:

- Avoidance of disruption to fish migrations
- Restoration / maintenance of longitudinal continuity

Application: All weirs and dams at which significant volumes of water are diverted from the main channel. Conditions for operation should be applied by planning and regulatory authorities.

Feasibility: Difficult to apply to existing situations where excessive abstractions have been taking place for some time. Difficult for regulatory authorities to ensure that specified conditions are adhered to. Adequate discharge to fish pass may not meet residual flow requirement of the depleted section.

Effectiveness: Should produce significant improvements in situations where fish passes and other installations have been operating inefficiently due to inadequate compensation flows and related factors. Conditions are likely to be site specific in relation to residual flow regime necessary to permit fish movements.

Specification/Description: Anon (2007b); Anon (2000c).

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