Final Report **Project WFD56**

Development of hydro-morphological improvement targets for surface water bodies

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SNIFFER
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EXECUTIVE SUMMARY

SNIFFER WFD 56: Development of hydro-morphological improvement targets for surface water bodies (October, 2005)

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Background to research

One of the aims of the Water Framework Directive (WFD) is to achieve 'good ecological status' in all surface water bodies by 2015 and also to prevent deterioration in the status of these water bodies. This project concentrates on water bodies which may be at risk of failing to achieve good ecological status due to man-induced hydro-morphological pressures and, as a result, the works may have to be carried out to remove or mitigate those pressures.

The classification of the ecological status of a surface water body is based on: biological elements, hydro-morphological elements supporting the biological elements and chemical and physico-chemical elements supporting the biological elements. The hydro-morphological quality elements must be taken into account when assigning water bodies to the high ecological class and the maximum ecological potential class. For other status/potential classes, the hydro-morphological elements are required to have 'conditions consistent with the achievement of the values specified for the biological elements'. Thus the assignment of water bodies to the good, moderate, poor or bad status/ecological potential classes may be made on the basis of the monitoring results for the biological quality elements. This is because, if the biological quality elements relevant to good, moderate, poor or bad status/potential are achieved then, by definition, the condition of the hydro-morphological quality elements must be consistent with that achievement and would not affect the classification of the ecological status/potential.

For the purposes of the WFD the categories of surface water bodies are: rivers, lakes, transitional waters and coastal waters. If water bodies are seen to be at risk of failing environmental objectives, actions have to be taken by 2015 to ensure that they meet the appropriate standards. In this report these actions are referred to as 'measures' or 'programmes of measures'.

As part of the implementation of the WFD, guidance documents have been prepared on the analysis of pressure and impacts within the characterisation of water bodies (Guidance for the analysis of Pressures and Impacts in accordance with the WFD, 2003 and Analysis of Pressures and Impacts, 2003). This characterisation has already been carried out for Scotland (SEPA, 2005). That study reviewed the following pressures and assessed their impacts on water bodies:

point source pollution,
diffuse source pollution,
abstraction and flow regulation,
morphological alterations,
alien species.

The present project is concerned with water bodies that are considered to be at risk of failing to achieve good ecological status due to hydro-morphological pressures and the measures that may need to be taken to mitigate these pressures.

Objectives of research

The objective of the project was to identify the potential restoration and mitigation targets which could be achieved to meet the requirements of the Water Framework Directive (WFD).

This project reviewed the water resource and morphological risk assessment preliminary results and identified what potential restoration targets may be achievable when assessing improvement measures for those water bodies that are seen to be at risk of failing environmental objectives as a result of significant hydro-morphological pressures. The project assessed potential mitigation measures required to achieve good ecological status. The project assessed potential costs of carrying out the proposed measures.

Key findings and recommendations

Key words: Water Framework Directive; Hydro-morphology; Surface waters, Rivers, Lakes, Transitional waters, Coasts

This project is concerned with the measures that will need to be taken for water bodies that are considered to be at risk of failing to achieve good ecological status or good ecological potential due to hydro-morphological pressures. SEPA has already carried out a study of the Pressures and Impacts on Scotland's Water Environment (SEPA, 2005). The results of that study have been reviewed as part of the present project. There was general support, from the project, for the earlier review that had been carried out. The Pressures and Impacts Study identified water bodies that are at risk of failing to achieve Good Ecological Status (GES) due to the presence of one or more pressures. It is possible, however, that when each water body is considered in further detail, a number of these water bodies will be considered to be achieving GES, despite the presence of the pressures. For these water bodies no action will be required to mitigate or remove the pressures for the water body to achieve GES.

This project has detailed potential measures that may be carried out to mitigate or remove the identified hydro-morphological pressures. These measures have been assessed in terms of:
a) their ability to reverse the pressure
b) the potential for the measures to result in morphological change
c) the feasibility of implementing the measures.

A literature review has been carried out to identify evidence for the impact of the proposed measures. This showed that much of the scientific work that has been carried out relates measures to their impact on the river morphology but there are very few studies which relate measures to their impact on the ecology. For some measures there is scientific support for the impact on ecology but the impact of other measures have not been studied and so there is no underpinning scientific support for these measures. This may reflect the lack of research in these areas rather than suggest that these measures are ineffective.

A series of field visits to selected sites were carried out to validate the measures that had been proposed to address the identified pressures. These site visits confirmed that the proposed measures were appropriate. The field visits also confirmed that some water bodies that have been identified as being at risk of failure to achieve GES due to hydro-morphological pressures may still be achieving good ecological status.

The time scales for achieving ecological improvement is also of importance. In some systems there may be a significant time between measures being carried out and the impact on the hydro-morphology being fully achieved. This delay may depend upon the nature of the measure and upon the nature of the water body. Once the hydro-morphological improvement has been achieved there may be a further delay before there are changes in the ecological system. Thus, it may take a significant period of time before Good Ecological Status is achieved.

The project has developed a procedure for assessing the likely costs of implementing the measures. For each measure a 'unit' cost has been derived which is normally expressed as a cost per metre or per square metre of water body. These unit costs have been derived from published data or the experience of project team members.

The water bodies considered where those that were thought to be potentially at risk of failing to achieve Good Ecological Status, excluding Heavily Modified Water Bodies, Artificial Water Bodies and those pressures that may fall under Q and S III. Using the unit costs, the cost of addressing the identified pressures for all the above water bodies has been estimated.

Costs have been estimated on the basis of an average cost for each measure taking into account the potential size of the water body and the length or area affected. In reality the costs for particular locations will vary widely depending upon the particular circumstances. The estimated cost reflects an estimate of the average cost averaged over a large number of sites. Thus the unit costs should not be used to assess the costs for individual schemes, which may be larger or smaller. Where a number of measures may be used to address a particular pressure an assessment has been made of the relative mix of different types of work based on experience and published data. To determine the overall costs, the costs for each water body were then summed to determine the total cost for each water body. This data is presented separately in a series of spreadsheets.

A number of the hydro-morphological pressures may cause water bodies to fail to meet good ecological status arise from current agricultural practises, such as, intensive land use adjacent to the water body. It may be that the measures required the remove or mitigate these pressures will not have to be funded and carried out by SEPA but may be addressed by others, such as the local landowner. To motivate others to do such work, however, SEPA may need to embark on suitable programmes of education and training. If SEPA wish to adopt this approach then it is recommended that an allowance should be made for the costs of providing suitable education and training programmes.

To implement the requirements of the WFD there will be a need for setting targets and monitoring with respect to hydro-morphological pressures. The problems of doing this are discussed and recommendations made. Using an assessment of habitat is based on the belief that habitat sets the context for the biological communities and that the physical habitat sets the framework for ecological systems. There are a number of existing methods based on an assessment of the geomorphic character of a river or stream, for example, geomorphic River Styles and the Rosgen classification. In addition there are methods which directly address the physical nature of the habitat, such as the US EPA method HABSCORE and the River Habitat Survey (RHS). These are based on the assumption that the quality and quantity of available physical habitat has a direct influence on the biotic community. At present the understanding of the linkages between ecology and geomorphology for water bodies within Scotland does not seem to be sufficient to support methods which concentrate on geomorphology, such as Geomorphic River Styles or Rosgen. There is not the evidence, however, to suggest that methods that are based on detailed surveys of biological communities, such as RIVPACS, take sufficient account of the physical influences. This tends to support that use of methods such as HABSCORE or RHS. A recently approved CEN standard on river hydromorphology (EN 14614) has been developed to enable surveys of rivers to be carried out using a common set of features in Europe. The RHS approach conforms to this standard. This system may offer potential for use by SEPA.

An existing approach to setting targets for rivers is provided by the River Habitat Objectives (RHOs), which are based on the premise that improvements in river habitats will produce ecological benefits.

It must be recognised that setting well-informed habitat objectives requires a good information base. To set targets one needs a method to assess what habitat character is required to achieve Good Ecological Status. The use of RHS cluster analysis provides a means of achieving this.

In the future there will be a need to assess if measures that have been implemented have been successful in improving the ecological status of a water body. For rivers the RHO approach may provide a quantifiable means of achieving this through the use of the River Habitat Quality scores.

Account Should be taken of the fact that there is currently a process underway to extend RHS to Geo-RHS. By explicitly taking account of geomorphology this may be an appropriate approach to assessing hydromorphological processes.

It has to be recognised that whatever approach is adopted it will be necessary to set up a system of accurately recording data, developing standard recording methods and implementing appropriate QA procedures.

Less work has been done on approaches for lochs, transitional waters and coasts. The lake equivalent of the RHS, a Lake Habitat Survey (LHS), is currently under development. It is expected to provide a basis for providing an approach to lakes.

In transitional and coastal waters there is no equivalent to the RHS. The existing classification systems applied by SEPA in transitional and coastal waters primarily focus on the achievement of water quality objectives and ensuring that biological quality is not impaired. The closest existing regime is probably the setting of conservation objectives for European Marine Sites under Regulation 33 of the Habitats Regulations. There is a need to develop monitoring tools that can detect changes in ecological elements related to hydromorphological modifications. Such tools should, therefore, as a minimum, be able to assess and be sensitive to:

Changes between types of ecological element within a water body,
Changes in extant (absolute abundance) of ecological elements within a water body,
Changes in composition an abundance of all ecological elements within a water body.

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APPENDICES

1 INTRODUCTION TO THE WATER FRAMEWORK DIRECTIVE

One of the aims of the Water Framework Directive (WFD) is to achieve 'Good Ecological Status' (GES) in all surface water bodies and also prevent deterioration in the status of these water bodies by 2015. Where water bodies have been subject to man-induced hydro-morphological pressures this may mean that to achieve GES works have to be carried out to remove or mitigate those pressures. The WFD recognises, however, that many water bodies have been subject to major physical alterations in order to allow for a range of water uses, for example, navigation, water supply, water regulation, flood protection and land drainage. The hydro-morphological changes required to satisfy these uses may mean that GES may not be achievable. As a result, the concept of a Heavily Modified Water Body (HMWB) was introduced. A surface water may be designated a HMWB to allow the continuation of the specified use of the water body. In this case it is required that the water body achieves derogation from 'good ecological status' to 'good ecological potential'. However, derogation to good ecological potential will only be considered if ultimately the measures required to achieve good ecological status turn out to be disproportionately costly.

The classification of the ecological status of a surface water body is based on: biological elements, hydro-morphological elements supporting the biological elements and chemical and physico-chemical elements supporting the biological elements. The value of the hydro-morphological quality elements must be taken into account when assigning water bodies to the high ecological class and the maximum ecological potential class. For other status/potential classes, the hydro-morphological elements are required to have 'conditions consistent with the achievement of the values specified for the biological elements'. Thus the assignment of water bodies to the good, moderate, poor or bad status/ecological potential classes may be made on the basis of the monitoring results for the biological quality elements. This is because, if the biological quality elements relevant to good, moderate, poor or bad status/potential are achieved then, by definition, the condition of the hydro-morphological quality elements must be consistent with that achievement and would not affect the classification of ecological status/potential.

There will be a requirement to monitor and assess hydromorphological quality elements for the range of status boundaries, for example:

- to determine the amount of loss of habitat/morphological alteration (and therefore dependent biology) from a range of activities;
- to assess "substantial physical alteration" in order to identify provisional HMWB's.

In assessing proposed future changes it may be difficult to consider the ecology of a water body directly and so reliance may need to be placed on surrogates, such as physico-chemical, hydrological and morphological criteria. This means that hydro-morphological criteria will be needed to define the high / good boundary as at High status these quality elements are protected in their own right. In addition, however, SEPA will also need hydro-morphology criteria for the good / moderate / poor / bad boundaries in order to have a system which avoids, or anticipates, deterioration in ecological quality as a result of proposed activities and which will form the basis of setting licences, including in circumstances when derogations for less stringent environmental objectives apply.

For the purposes of the WFD a number of categories of surface water bodies have been identified. These are: rivers, lakes, transitional waters and coastal waters.
Where water bodies are seen to be at risk of failing environmental objectives, steps have to be taken by 2015 to ensure that they meet the appropriate standards. These steps are known as 'measures' or 'programmes of measures'.

As part of the implementation of the WFD, guidance documents have been prepared on the analysis of pressures and impacts within the characterisation of water bodies (Guidance for the analysis of Pressures and Impacts in accordance with the WFD, 2003 and Analysis of Pressures and Impacts, 2003). A document has also been produced specifically for Scotland: Pressures and Impacts on Scotland's Water Environment (SEPA, 2005).

This project is concerned with the measures that will need to be taken for water bodies that are considered to be at risk of failing to achieve GES due to hydro-morphological pressures.

The implementation of the WFD up to 2015 by SEPA depends upon the context within which SEPA has to operate. This depends upon decisions that have yet to be taken and so are, as yet, unknown. Examples of such issues include: the outcomes of Quality and Standards III, the possible reform of Common Agricultural Policy, the scope for rural development funding and the development of the concept of sustainable flood risk management.

The project has reviewed the preliminary results of studies of water resource and morphological risk assessments and has identified what potential measures are achievable for those water bodies that are perceived to be at risk of failing environmental objectives as a result of hydro-morphological factors and their likely associated costs.

2 REVIEW OF PRESSURES AND IMPACTS

2.1 Review of study on pressures and impacts

2.1.1 Description of process for assessing pressures

An earlier SEPA study has already identified the Pressures and Impacts on Scotland's Water Environment (SEPA, 2005). This study reviewed the following pressures and assessed their impacts on water bodies:

- point source pollution,
- diffuse source pollution,
- abstraction and flow regulation,
- morphological alterations,
- alien species.

For each pressure, water bodies were allocated to the following classes:

- At risk:1a, Water body at significant risk of not meeting good status
- At risk: 1b, Water body probably at significant risk but for which further information is needed to make sure this view is correct,
- Not at risk: 2a Water bodies probably not at significant risk
- Not at risk: 2b Water bodies not at significant risk.

The risk assessments were carried out using a variety of data. Some information was available from River Habitat Surveys and the System for Evaluating Rivers for Conservation (SERCON) monitoring, however, these sites only cover a proportion of Scotland's rivers. In order to identify any further pressures, a map-based approach was used to identify morphological alterations. By examining maps for features such as river straightening, land claim, presence of ports and harbours, and using local knowledge, additional water bodies at risk were identified. In addition, site visits were made to a small proportion of the 'at risk' water bodies.

The conclusions of the Pressures and Impacts Study (SEPA, 2005) on the impact of morphological alterations are summarised in the following Tables. Note that the figures in the Tables include HMWBs and AWBs.

Table 2.1 River water bodies affected by morphological alterations

Reporting category	No of water bodies	% of number	Length (km)	% of Length
1a	296	12.4	2800	11.1
1b	484	20.3	5630	22.4
2a	170	7.1	2074	8.3
2b	1430	60.1	14,621	58.2
Total	2380	100	25125	100
Total at risk	780	32.7	8430	33.5

Table 2.2 General industry sectors affecting 1a and 1b river water bodies

General industry sector	No of water bodies
Agriculture and forestry	426
Operation of fish hatcheries and fish farms, commercial fishing	27
Mining and quarrying	4
Manufacturing	18
Electricity, gas and water supply	108
Construction	1
Transport, storage and communication	48
Sewage and refuse disposal	19
Land drainage, land claim, flood defence, urbanisation	263

Table 2.3 Loch water bodies affected by morphological alterations

Reporting category	No of water bodies	% of number	Length (km)	% of Length
1a	93	27.8	335	33.8
1b	37	11.1	113	11.4
2a	6	1.8	13	1.3
2b	198	59.3	532	53.6
Total	334	100	992	100
Total at risk	130	38.9	448	45.2

Table 2.4 General industry sectors affecting 1a and 1b lake water bodies

General industry sector	No of water bodies
Agriculture and forestry	27
Manufacturing	1
Electricity, gas and water supply	85
Transport, storage and communication	7
Sewage and refuse disposal	11
Land drainage, land claim, flood defence, urbanisation	19

Table 2.5 Transitional water bodies affected by morphological alterations

Reporting Category	No of water bodies	% of number	Length (km)	% of Length
1a	12	24.0	558	56.1
1b	7	14.0	47	4.8
2a	3	6.0	60	6.0
2b	28	56.0	329	33.1
Total	50	100	995	100
Total at risk	19	38.0	605	60.9

Table 2.6 General industry sectors affecting 1a and 1b river water bodies

General industry sector	No of water bodies
Manufacturing	1
Construction	1
Transport, storage and communication	3
Land drainage, land claim, flood defence, urbanisation	18

Table 2.7 Coastal water bodies affected by morphological alterations

Reporting category	No of water bodies	% of number	Length (km)	% of Length
1a	14	3.1	1224	2.6
1b	26	5.7	2272	4.8
2a	40	8.8	20770	43.5
2b	377	82.5	23443	49.1
Total	457	100	47709	100
Total at risk	40	8.8	3496	7.4

Table 2.8 General industry sectors affecting 1a and 1b river water bodies

General industry sector	No of water bodies
Operation of fish hatcheries and fish farms, commercial fishing	31
Construction	1
Sewage and refuse disposal	1
Land drainage, land claim, flood defence, urbanisation	10

2.1.2 Critique of process of assessing pressures

The assessment of the likely impact of hydro-morphological pressures was based on an assessment of the degree of anthropogenic, morphological change. Implicit in this approach is a belief that if the morphology of the water body has been impacted then there is likely to be an impact on the ecology of the water body. This belief is widely supported and underlies the movement encouraging the restoration and rehabilitation of water bodies. The basic premise for the restoration and rehabilitation movement is that changes to the morphology of water bodies in the past has led to a degradation of their ecology and returning the morphology to a more natural state should lead to an improvement in the ecology.

Within the general support for the procedures that have been adopted, there are specific water bodies that may be exceptions. One class of exceptions is water bodies which have been subject to morphological pressures but which may still be achieving good ecological status. There are reaches of rivers which have been subject to the installation of bank protection and where there are major bridge crossings at some locations but, despite all these apparent pressures, the river may well be in good ecological status. Indeed were efforts made to mitigate these pressures they might cause more ecological damage than benefit. The implication is that detailed study of particular water bodies that have been identified as being subject to hydro-morphological pressure may reveal that they are already achieving good ecological status and that no measures need to be taken. This issue arises in Section 4.3 in which the field work is discussed.

Another issue is whether the changes that have taken place in a water body are reversible or not. It may be that the changes that have taken place are irreversible in which case removing the morphological pressure may not in itself lead to the achievement of good ecological status.

2.2 Heavily Modified Water Bodies (HMWBs) and Artificial Water Bodies (AWBs)

SEPA have provided the project with a provisional list of Heavily Modified Water Bodies (HMWBs) and Artificial Water Bodies (AWBs). The assessment of the potential measures required to achieve good ecological potential is difficult as they are specific both to the nature of the water body and to the use that is being made of the water body. It is understood from SEPA that, at the moment, there is insufficient data available to be able to determine the measures that are required to achieve good ecological potential for these water bodies. In the absence of this data we have been advised by SEPA to remove the HMWBs and AWBs from the analysis described below.

The pressures that lead to waterbodies being designated as HMWBs are similar in character and effect to many of the pressures considered above. This means that many of the measures that are considered below may be applied to HMWBs to ensure that the waterbody achieves good ecological potential (GEP). Within the context of this study it has not been possible to incorporate HMWBs and AWBs as the characterisation process only identifies such water bodies as being 'at risk' of not meeting GEP. At the present there is no systematic method for assessing whether the pHMWB sites are already at GEP or not nor of assessing what measures may be needed for those that don't achieve GEP.

3 CRITERIA TO BE APPLIED TO THE MEASURES TO ADDRESS THE IDENTIFIED PRESSURES

3.1 Introduction

If there are a number of water bodies, each subject to one or more pressures then the issue arises as to how to prioritise the water bodies. The prioritisation may be on the basis of one or more criteria and these may be analysed in a number of ways.

In prioritising actions on water bodies there are a number of potential objectives that may be considered. The issues that need to be considered include:

- technical issues to do with the ability to address the identified pressure(s),
- issues to do with the cost of any proposed works,
- issues to do with the socio-economic environment of the water body and
- issues to do with the achievement of good ecological status.

Criteria based on these issues are considered in more detail below.

3.2 Criteria to apply to the range of pressures and impacts

a) Ability to address identified pressure(s)

In Table 2, potential measures are listed to address given pressures. The proposed measures have different degrees of impact on the identified pressure. Thus, all the proposed measures under ‘Constriction’ are assessed to have a ‘High’ potential to result in a hydro-morphological change while all the proposed measures under ‘Dredging’ are assessed to have a ‘Low’ potential. If the priority is to achieve hydro-morphological change then there would be advantages to giving priority to those water bodies which there is a high potential for achieving hydro-morphological change. Thus one would give priority to water bodies subject to those pressures for which the corresponding measures have a ‘High’ potential for hydro-morphological change.

A difficulty arises with those pressures for which there are a number of possible measures but the different measures have different potential to result in hydro-morphological change. In general, the different measures normally have different costs associated with them. Thus, for example, the measures identified to address the pressure ‘Culverting’ range from the removal of the culvert to habitat improvement works. These measures have different potential to reverse the pressure and their associated costs are very different. The decision as to which is the appropriate measure to carry out depends upon specific site conditions and cannot be taken on a generic basis. To prioritise on the basis of the ability to address the identified pressure one then has to make an assumption about which measures are likely to be carried out ‘on average’.

b) Total cost per water body

One criteria that can be considered is the total cost per water body of addressing the pressures. Thus priority would be given to those water bodies for which the costs were lowest. This would mean that for a given sum of money the largest number of water bodies would be treated. As water bodies differ in overall length then this would tend to give priority to the smaller water bodies.

c) Cost per km of water body

An alternative approach would be to prioritise on the basis of the cost per km of addressing the pressures. This would mean that for a given sum of money the longest length of water bodies would be treated. This would give priority to those water bodies for which the unit cost of addressing the pressure was smallest. The measures with the lower unit costs tend to be those which have a lower potential for resulting in hydro-morphological change. Thus while prioritising on this basis may treat the longest length it might not maximise the hydro-morphological improvement

d) Single or multiple hydro-morphological pressures

One possibility is to give priority to those water bodies that are only subject to a single hydro-morphological pressure over those water bodies that are subject to two or more hydro-morphological pressures. This would ensure that priority was given to those water bodies for which there was the best opportunity of addressing the hydro-morphological pressures. This criteria is not independent of the costs related criteria as the costs of addressing the pressures on a water body will depend upon the number of pressures that have to be addressed

e) Risk that the water body will fail to achieve GES due to other pressures

A number of water bodies may be subject to pressures other than hydro morphological ones, for example, water quality pressures. In this case, even if the hydro-morphological pressures are addressed, there may be a risk that the water body may not achieve GES due to these other pressures. If one wishes to reduce the risk that hydro-morphological work is carried out and then the water body does not achieve GES then one should give priority to those water bodies that are not at risk due to other pressures.

f) Socio-economic factors

There may be the desire to give priority to those water bodies that are associated with socio-economically deprived areas. In the characterisation data there is a measure of socio-economic status of areas associated with water bodies. The poorest socio-economic areas tend to be associated with urban areas. The cost of implementation of measures in urban areas tends to be higher than in rural areas due to the constraints and difficulties in working in urban areas.

g) Feasibility

There are some measures that could be used to address specific pressures but in practise they may not be feasible. For example, if the pressure arises from an impoundment then one measure to address this is to remove the impoundment or if an urban river has been straightened and there are now major buildings along both banks then one measure is to re-meander the river. In both cases the measures are possible but have a low feasibility.

3.3 Methods of analysis of the criteria

From the discussion of the potential criteria above it is clear that there would appear be no single criteria which provides an adequate basis for prioritising proposed measures on water bodies. In this case, it would seem that the best approach would be to adopt some form of Multi-Criteria Decision Making. In this approach decisions are made based on a number of different criteria. These criteria should be:

a. complete and exhaustive,
b. independent.

For the purposes of the present project it is proposed that the following criteria could be used:

a) Potential to achieve hydro-morphological change:
b) Feasibility
c) Cost per km of water body
d) Risk that water body will fail to achieve GES due to other pressures
d) Socio-economic class

There are a wide range of methods that can be used in Multi-Criteria Analysis but it is suggested that the method used be based on using multiplicative weights on each criteria and the scores on each criteria being added to give an overall score for each water body. The water bodies can be then prioritised on the basis of their scores (Yoon and Hwang, 1995). The weights selected for the criteria should reflect SEPA’s priorities.

4 REVIEW OF POTENTIAL MEASURES FOR MORPHOLOGICALLY IMPACTED WATER BODIES

4.1 Introduction

The Pressures analysis described above identified the morphological pressures which could potentially lead to a water body failing to achieve good ecological status. This then raises the issue of what measures, if any, that can be taken to mitigate or remove these pressures. These measures should lead to an improvement in the ecological status of the water body and have the potential to lead to the achievement of good ecological status. The proposed hydro-morphological measures may not, by themselves, be sufficient to achieve good ecological status as any water body may be subject to multiple pressures, for example diffuse pollution, in addition to the identified hydro-morphological pressures.

Intervies et al (2004) present a framework for assessing proposed measures. This approach was discussed within the Project Team. It was concluded that the approach gave a rational, structured approach to the selection of measures that could be used for specific water bodies but that it was felt that the present level of knowledge meant that it was not possible to carry out the approach on a generic basis. It was decided that the project should adopt an approach based on past experience and published data.

4.1.1 Measures for rivers and lochs

As part of the project documentation SEPA provided a note entitled: ‘Assessment of potential restoration options for morphologically impacted water bodies’ which outlined potential measures for a range of pressures. The measures proposed to address the identified pressures were reviewed by the project and the measures were assessed for:

a. their ability to reverse the hydro-morphological pressure
b. their potential to result in an hydro-morphological change.
c. the feasibility of implementing the measures,

see Tables 4.1 and 4.2.

Table 4.1 Assessment of measures for rivers

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
River substrate manipulation	Removal of artificial bed material (concrete – gabion)	High	High	Med	Remove artificial material	
	Cover artificial bed material with natural substrate	Low	Low	Med	Remove artificial material	
Bed and bank reinforcement	Removal of Hard engineering (and not replacing it with something) Replacement with more natural solutions (soft engineering structures) (including cost of above option)	High Med	Med Low	Low High	Willow spilling Log and toe geotextile revetment with willow slips Willow Mattress revetment Plant roll revetment Hurdle and coir matting revetments Bank revetment (steel piling and coir rolls)	Limited evidence on specific techniques but a number on the general role of vegetation for bank protection and its effectiveness (Bowie, 1982; Masterman & Thorne, 1992; Sheilds et al. 1995 etc)
River resectioning	Cessation of maintenance, allow bed, banks and riparian zone to recover natural profile/structure	High	High	Med		Limited scientific papers on restoring meanders etc. A limited number of papers exist on identifying meander parameter restoration procedures (Rinaldi et al, 1997) along with a number of case studies on restoring meanders
	In-stream habitat enhancement measures	Mrf	Med	High	Stone riffles Low cost groynes Current deflectors	
	Seeding/Planting on margins, banks and in riparian zone to create natural bank features/structures	Low	Low	High		
River straightening	Restore straightened sections (put meanders in) Assume that will have to correct bed level as well	High	High	Low	Re-meandering Re-meandering Re-meandering Re-design straight channel to sinuous multi-channel river Restore channel Reconnection of cut-off meanders	
	Make the channel narrower Increase flow diversity Assume deflector every 5 channel widths	Low	Low	Low	Current Deflectors Aquatic ledges Low cost groynes Aquatic ledges	
	Leave river to reform pools and riffles	Med	Med	Med		
	Re-connecting existing meanders to main channel	High	High	Low	Reconnecting remnant meanders	
	Initiate natural planform/meanders	High	High	Med	Assisting natural recovery	
	Introduction of in channel structures to increase flow diversity Assume measure every 5 channel widths				Stone riffles Low cost groynes Current Deflectors	
River realighment	Re-connecting existing meanders to main channel	High	High	Low	Reconnecting remnant meanders Reconnecting cut-off meanders	
	Initiate natural planform/meanders	High	High	Med		
	Introduction of in-channel structures to increase flow diversity	Med	Med	High	Stone riffles Low cost groynes Current deflectors	

Table 4.1 Assessment of measures for rivers (continued)

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
River channelisation	Re-connecting existing meanders to main channel	High	High	Low	Reconnecting remnant meanders Reconnection of cut-off meanders	Limited scientific papers on restoring meanders etc. A limited number of papers exist on identifying meander parameter restoration procedures (Rinaldi et al, 1997) along with a number of case studies on restoring meanders
	Initiate natural planformm,eanders	High	High	Med		
	Introduction of in channel structures to increase flow diversity	Med	Med	High	Stone riffles low cost groynes Current deflectors	
Culverting	Removal of culverts (link to flood reduction measures)	High	High	Low	Deculverting	Scientific evidence on the removal of culverts is very limited – no papers were found in the most common journals
	Daylighting	Med	Med	Med		
	Improve connectivity to existing culvert, allow natural substrate bed material	Loe	Med	High		
	Habitat improvement measures	Low	Low	High	e.g. fish passes, ledge creation	
Dredging	Cease dredging activities	Low	Low	Med		Numerous papers exist on the effects of dredging on the physical habitat particularly on macroinvertebrates
	Reduce intensity and timing of dredging activities	Low	Low	Med		
Flow manipulation	Re-introduce natural flooding regime	Med	Med	Low		Numerous papers exist on the effects of flow on the biology of rivers
	Introduce minimum flows			High		
Impounding	Removal of dams	High	High	Low		Numerous journals exist on the effects of dams on fish access. Scientific evidence on fish passes is very limited
	Build in fish passages	High	None	High	Pool and traverse fish pass	
	Improve existing fish passages	Med	None	High	Weir bypass via ditch Notch cut in weir	
	Allow passage of sediment downstream	Med	Med	Low		
	Removal of weirs	High	High	Low	Removal of low weir/modification work	
Constriction	Removal of weirs	High	High	Low	Removal of low weir/modification work	
	Replace current bridges with clear span bridges	High	High	Low		
Intensive use	Introduce buffer zones adjacent to river	High	Med	High		
	Reduce grass cutting and other vegetation management	Low	Low	High		
	Removal of embankments (to reconnect floodplain)	High	High	Low	Removing and setting back floodbanks	
	Allow natural flood storage on floodplain (unmanaged retreat)	High	High	Med	Floodplain wetland mosaic	
	Promote flood storage (links to recreation opportunities) (LINK)	High	High	High	Floodplain scrapes Loch flood storage basin Floodplain pond	
Removal of natural barriers	Stop removal of natural barriers e.g. woody debris, log jams etc.	High	High	Med		
Modifications to sediment regime	Improve sediment management within catchment through land-use management	High	High	Med		
	Reduce erosion in riparian zone	High	High	Med		
	Introduction of buffer zones	Med	Med	high		

Table 4.2 Assessment of measures for lochs

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
Channelisation / realignment / straightening – channelisation	Restore sections that have been straightened	High	High	Low	Re-meandering Re-design straight channel to sinuous multi-channel Restore channel	Limited scientific papers on restoring meanders
	Introduce channel structures to increas4e flow diversity	Med	Med	High	Current deflectors, groynes, aquatic ledges	
	Initiate natural planform	High	High	Med	Assist natural recovery	
	Regrade channel	Low	Low	Med		
Construction / structures – embankments	Remove hard engineering and replace with more natural methods	Med	Low	high		
Construction / structures - unspecified						Numerous papers on the effects of dredging on physical habitats and macro invertebrates
Dredging – resulting in removal of sediment	Cease dredging activity	Med	Low	Low		Numerous papers on effects of dams on fish access
	Reduce intensity and timing of dredging	Low	Low	Med		
Impounding – sluice	Remove structure	High	High	Low		
	Construct fish pass	High	None	High		
Impounding – weir / dam	Remove structure	High	High	Low		
	Construct fish pass	High	None	High		
Intensive use – cultivating / planting to bank	Introduce buffer zones	High	Med	High		
Intensive use – grazing	Introduce buffer zones	High	Med	High		
Reinforced – unspecified	Replace with more natural bank protection methods	Med	Low	High		Limited evidence on specific techniques
Resectioned – bed	Re-grade bed	High	High	med		

In considering the implementation of measures to address identified morphological pressures it is important that the pressure and the measures are considered at both the local and the wider scale, be it catchment or coastal cell. Though the manifestation of a pressure may be local the fundamental cause of a problem may lie elsewhere or may be distributed rather than local. In this case the appropriate measure may need to address scales which are larger than the scale of particular water bodies.

The WFD characterisation is based on discrete water bodies. The pressures on each water body and the risk that these pressures are such that the water body may not achieve GES has been assessed. In the following measures are described that potentially could be used to mitigate particular pressures. There is a risk that this will encourage too narrow a perspective in the assessment of potential measures. It may be that the most appropriate approach would be to consider mitigation strategies within the context of the natural system, for example, on a catchment basis for rivers and lochs or in the context of a coastal cell for coastal water bodies. This approach would be preferable to addressing individual pressures water body by water body. It is recommended that the assessment of potential mitigation measures is carried out within the context of the natural appropriate unit, be it catchment or coastal cell, rather than by addressing issues reach by reach.

This suggests that the approach that should be adopted is that the pressures should be reviewed within the natural unit, be it catchment or coastal cell. The pressures need to be understood within this context and within the natural processes of the system before mitigation measures are formulated on a water body by water body basis.

The fluvial systems is a two-phase system in which water and sediment move through the channel network from erosional source to depositional sink. The transfer of sediment through the system is considerably more unsteady and non-uniform than the flow of water, and has been likened by geomorphologists to the operation of a 'jerky conveyor belt'.

In the past, many engineering and river management schemes were invoked in ways that ignored the continuity of sediment transfer in the fluvial system. Often, reach-scale projects had the effect of punctuating or disrupting sediment transfers, resulting in disconnection of the natural links between sediment sources and sinks. The result of such actions is to generate new areas of sediment accumulation where sediment movement is impeded and to leave areas downstream of these new sediment sinks under supplied – promoting to scour by sediment starved flows.

Modern approaches to catchment planning call for system-wide approaches in the case of *flood management* and it is now being recognised that this philosophy must be extended to system-wide *sediment management* if problems of long-term channel instability and the need for heavy and unsustainable channel maintenance are to be avoided.

It follows that any proposal to improve the ecological status of a reach of river through alterations to its physical condition (morphology) or fluvial processes (hydraulics and sediment dynamics) must be undertaken within the context of a catchment-wide plan for sediment management. Designers can only bring forward sustainable solutions to reach-scale sediment and morphology-related issues if they do so by reference to a coordinated and comprehensive scheme for managing sediment transport and transfer at the system-scale. This is in essence a 'joined-up' approach that recognises the importance of sediment continuity and connectivity in the fluvial system.

Thus, when considering rivers and lochs it is important to consider the whole of the catchment, not just the water bodies within the catchment. Land use within the catchment will affect the nature of the run-off to the water bodies and the sediment load. It follows that land use within the catchment as a whole may affect the ability to achieve GES.

4.1.2 Measures for transitional waters

Measures to address pressures on transitional waters have also been identified.

Table 4.3 Assessment of measures for transitional waters

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
Channelisation/realignment/straightening (unspecified)	Managed realignment	high	high	low	Removal of seawall	Numerous case studies exist. CIRIA guidelines on engineering to realignment
				med	Put culverts through seawall	
				med	Managed retreats	
	Construction of breach/spillway	high	high	med	Construction of breach or spillway	
	Re-connecting existing meanders to main channel	high	high	low	Reconnecting remnant meanders	Limited scientific papers on restoring meanders etc. A limited number of papers exist on identifying meander parameters and relationships for use in meander restoration procedures (Rinaldi et al. 1997) along with a number of case studies.
	Footbridge construction	low	low	high		
	Initiate natural platforms/meanders	high	high	med	Assisting natural recovery	
Construction/structures (embankments)	Managed realignment	high	high	low	Removal of seawall	Numerous case studies exist. CIRIA guidelines on engineering to realignment
				med	Put culverts through seawall	
				med	Managed retreats	
	Construction of breach/spillway	high	high	med	Construction of breach or spillway	
	Rehabilitation of floodplain	high	high	med	Construction of breach or spillway	
	Removal of structures e.g. weirs, bridges etc.	high	high	low	Removal of weirs, bridges etc/modification work	
	Removal of hard engineering	high	med	low		
	Replacement with more natural solution (soft engineering structures)	med	low	med	Introduce saltmarsh wetlands	Limited evidence on specific techniques but a number on the general role of vegetation for bank protection and its
				high	Beach nourishment (sand, gravel or pebbles)	
	Reworking of slopes to form a more natural appearance	low	low			
Construction/structures (jetties, piers)	Removal of structures	low	low	low		
Construction/structures (unspecified)	Managed realignment	high	high	low	Removal of seawall	Numerous case studies exist (e.g. ABPmer, 2004). CIRIA guidelines on the engineering of managed realignment schemes (CIRIA (2004)
				med	Put culverts through seawall	
				med	Managed retreats	
	Removal of structures	high	low	low		
	Removal of hard engineering	high	med	low		
	Replacement with more natural solution (soft engineering structures)	med	low	med	Introduce saltmarsh wetlands	Limited evidence on specific techniques but a number on the general role of vegetation for bank protection and its
				high	Beach nourishment (sand, gravel or pebbles)	

Table 4.3 - Assessment of measures for transitional waters (continued)

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
Dredging (deposition of dredged material)	Cease dredging	high	med	low		Numerous papers exist on the effects of dredging on the physical habitat particularly on macroinvertebrates
	Beneficial use	low	low	med	Use material from dredging of channels, harbours for beneficial use (e.g. sediment recharge, trickle recharge, beach nourishment etc.)	An increasing number of beneficial use schemes are being promoted. Schemes using sand/gravel for beach recharge are now well established. A number of schemes for fine material are also being progressed successfully.
Dredging (resulting in removal of sediment)	Cease dredging	high	med	low		
	Reduce intensity and timing	med	med	med		
	Modify dredging regime and techniques	med	low	high	Use alternative techniques e.g. avoid overspilling, minimise drag-head disturbance, use silt screens etc.	Few alternative techniques are likely to reduce morphological impact although they could limit water quality impacts in some situations.
Dredging (unspecified)	Cease dredging	high	med	low		
	Reduce intensity and timing	med	med	med		
	Modify dredging regime and techniques	med	low	high	Use alternative techniques	As above
Flow manipulation (boulder placement)	Removal of structures	high	high	low		
Impounding (sluice/weir)	Removal of sluices/weirs	high	high	low	Removal of sluices and weirs/modification work	
	Build in fish passages	high	none	high	Pool and traverse fish pass	Numerous journal articles exist on the effects of dams on fish access. Scientific evidence on fish passes is limited.
	Improve existing fish passages	med	none	high	Weir bypass via ditch	
				high	Notch cut in weir	
	Allow passage of sediment downstream	high	med	low		
Reinforcement (concrete/rip rap)	Removal of hard engineering	high	med	low		
	Replacement with more natural solution (soft engineering structures)	med	low	med	Introduce saltmarsh wetlands	
				high	Beach nourishment (sand, gravel or pebbles)	

4.1.3 Measures for coastal waters

Measures to address pressures on coastal waters have also been identified.

Table 4.4 Assessment of measures for coastal waters

Specific pressures	Potential measures to address the pressure	Ability to mitigate the pressure	Potential to result in a beneficial hydromorphological change	Feasibility	Technique	Scientific evidence
Channelisation/realignment/straightening (unspecified)	Managed realignment	high	high	low	Removal of seawall	Numerous case studies exist. CIRIA guidelines on engineering to realignment
				med	Put culverts through seawall	
	Construction of breach/spillway	high	high	med	Construction of breach or spillway	
	Footbridge construction	low	low			
Construction/structures (any structure effectively fixing the line of sea defence or the position of the coastline)	Managed realignment	high	high	low	Removal of seawall	
				med	Put culverts through seawall	
	Construction of breach/spillway	high	high	med	Construction of breach or spillway	
	Rehabilitation of floodplain	high	high	med	Construction of breach or spillway	
	Removal of hard engineering	high	med			
	Replacement with more natural solution (soft engineering structures)	med	low	med	Introduce saltmarsh wetlands	Limited evidence on specific techniques but a number on the general role of vegetation for bank protection and its effectiveness (Bowie, 1982; Masterman & Thorne, 1992; Shields et al. 1995 etc). Numerious examples of success of beach nourishment. e.g. sand on
				high	Beach nourishment (sand, gravel or pebbles)	
				med	Offshore island as breakwaters	
				high	Planting if grasses (marram grass or dunes) or other plants suitable for hostile conditions	
	Reworking of slopes to form a more natural appearance	low	low			
Construction/structures (jetties, piers)	Removal of structures	low	low			
Construction/structures (unspecified)	Managed realignment	high	high	low	Removal of seawall	Numerous case studies exist (e.g. ABPmer, 2004). CIRIA guidelines on the engineering of managed realignment schemes (CIRIA (2004)
				med	Put culverts through seawall	
				med	Managed retreats	
	Removal of structures	high	low			
	Removal of hard engineering	high	med			
	Replacement with more natural solution (soft engineering structures)	med	low	med	Introduce saltmarsh wetlands	
				high	Beach nourishment (sand, gravel or pebbles)	
Dredging (deposition of dredged material)	Cease dredging	high	med			Numerous papers exist on the effects of dredging on the physical habitat particularly on macroinvertebrates
	Beneficial use	low	low	med	Offshore island as breakwaters	An increasing number of beneficial use schemes are being promoted. Schemes using sand/gravel for beach recharge are now well established. A number of schemes for fine material are also being progressed successfully.
				med	Use material from dredging of channels, harbours for beneficial use (e.g. sediment recharge, trickle recharge, beach nourishment etc.)	
Dredging (resulting in removal of sediment)	Cease dredging	high	med	low		As above
	Reduce intensity and timing	med	med	med		
	Modify dredging regime and techniques	med	low	med	Use alternative techniques	
Dredging (unspecified)	Cease dredging	high	med	low		As above
	Reduce intensity and timing	med	med	med		
	Modify dredging regime and techniques	med	low	med	Use alternative techniques	
Flow manipulation (boulder placement)	Removal of structures	high	high	med	Removal of grognes	
Reinforcement (concrete/rip rap)	Removal of hard engineering	high	med	med		
	Replacement with more natural solution (soft engineering structures)	med	low	high	Introduce saltmarsh wetlands	
					Beach nourishment (sand, gravel or pebbles)	

Measures to address specific pressures

1) River substrate manipulation

This pressure arises where the natural substrate has been removed or where it has been removed and replaced with an artificial bed material. Many in-stream habitats are determined by the substrate and so the absence of the natural substrate often has a major impact on the in-stream macrophytes, invertebrates and fish. The potential measures to address this pressure include:

a) the removal of any artificial bed and replacement with natural substrate
b) the placement of natural bed material on top of the artificial bed
c) the replacement of natural substrate if it has been removed.

In selecting the most appropriate measure and its implementation there are issues related to:

- the continuity of sediment movement upstream and downstream,
- the availability of suitable sediment material,
- the size and nature of bed features
- the potential mobility of sediment during a flood.

Pool-riffle sequences will naturally reform in channels where there is evidence that the substrate is regularly mobilised and where sediment of gravel size is available. When introducing substrate, however, the size of substrate is extremely important (Brookes and Sear, 1996).

When implementing these types of measures it is important that the specific nature of the river is taken into account when designing the details of the scheme. Examples of river substrate manipulation are given in River Restoration Centre (2002) but it should be remembered that these are for specific locations and may not be applicable to all river types.

2) Bed and bank reinforcement

This pressure arises when the bed or bank of the water body has been reinforced using artificial (hard) materials. As discussed above the absence of the natural substrate on the bed due to the presence of hard reinforcement often has a major impact on the range of habitats and hence the in-stream macrophytes and invertebrates. The potential measures to address this pressure include:

a) the removal of the reinforcement works. This assumes that the consequences or having no bed and bank reinforcement are acceptable in terms of potential erosion and consequent sediment release.
b) the replacement of the reinforcement works with more natural materials (soft engineering). In recent years there have been significant advances in the use of soft engineering techniques, including, for example, willow spilling, geo-textiles and coir matting. Soft engineering techniques can only be used for a limited range of flow conditions and may not be applicable in high flow velocity situations. With such forms of reinforcement there is a greater risk of failure than with traditional hard engineering methods and so they may not be practical in situations in which an increased risk of erosion is unacceptable. For examples see River Restoration Centre (2002).

In the context of transitional and coastal waters one option is to provide a breach or spillway to allow water to pass beyond the reinforcement works.

3) Channel resectioning

This pressure arises when the section of a channel is periodically modified, normally to increase the conveyance of the cross-section. The disturbance of the bed and banks often damages the bank and in-stream habitats affecting the nature and types of macrophytes and invertebrates. The potential measures to address this pressure include:

a) ceasing to carry out the maintenance work. This allows the bed, bank and riparian zone to develop to a more natural state. This assumes that the consequences of this, in particular in terms of channel conveyance are acceptable.
b) in-stream habitat enhancement measures. A wider diversity of flow conditions can be created by the use of small structures such as stone riffles, groynes and current deflectors, see Swales, 1994 and River Restoration Centre, 2002). This assumes that the consequences of this, in particular in terms of channel conveyance are acceptable.
c) seeding and planting on the banks and margins. This can help to create a wider diversity of flora and fauna on the banks and margins than might otherwise exist but the measure does not address the morphological issues or address in-stream habitats.

Keller (1978) has shown how modification of channel symmetry can be used to induce the development of bed forms by controlling cross-channel patterns of water movement.

4) Channel straightening

This pressure arises from changes to the plan form of the river or transitional water to make the plan form more regular. It tends to reduce the range of flow conditions within a reach and thus the diversity of the habitats. To address this pressure one has to re-establish the wide range of flow conditions. This may be done by establishing a less regular plan form or by carrying out in stream works to create flow diversity. In general, establishing a less regular plan form is more likely to provide widest range of flow conditions. This is often difficult and expensive to do in practise due to land requirements and constraints. It is often completely impractical in urban areas. Even if possible it is important to remember that the natural plan form of a river is determined by factors such as discharge, channel width, slope and sediment size. Thus the channel plan form cannot be selected arbitrarily. See Shields (1996) and Brookes and Sear (1996) for a discussion of the problems of designing restored reaches. It is possible to leave a channel to develop due to natural processes but this may generate large-scale dis-equilibrium during the period of adjustment (Hasfurther, 1985). There may be thresholds for the natural recovery of previously straightened streams, see Brookes (1987). As an alternative measure steps can be taken to develop a wider range of in-stream flow conditions, including allowing the development of pools and riffles.

A major issue that needs to be addressed when considering measures to address the pressure caused by channel straightening in rivers is the slope of the river system and the potential for upstream and downstream impacts (Brookes and Sear, 1996).

For examples see River Restoration Centre (2002).

Within the context of transitional waters one option is managed realignment or breaching of any defences to promote the development of more natural morphology.

5) Channel re-alignment

This pressure arises as a result of changes to the plan form of a river or transitional water. This tends to reduce the range of flow conditions within the reach and thus the diversity of habitats. The measures to address this pressure and the issues raised are the same as for Channel straightening discussed above.

6) Channelisation

This pressure arises as a result of works which converts a channel from a natural to an artificial form. This tends to reduce the range of flow conditions within the reach and thus the diversity of habitats. The measures to address this pressure and the issues raised are the same as for Channel straightening discussed above.

7) Culverting

This pressure results when river channels are put into culverts. Impacts arise from the reduction or complete absence of light and the artificial nature of the channel. This results in a significant impoverishment of the macrophytes and invertebrates. The presence of culverts may also inhibit the movement of fish. Thus a culvert may provide a barrier to movement upstream and downstream. The measures to address this pressure include:

a) the removal of the culvert. This frequently involves major engineering work and may have an impact on flood defence.
b) daylighting. This involves converting the system from a closed channel to an open channel. This can address the issue of the absence of light but does not necessarily affect the artificial nature of the channel.
c) connectivity can be improved by providing a natural substrate through the culvert. Many of the issues associated with this are covered in River substrate manipulation above.
d) habitat improvement. This normally can only partly mitigate the impact of the culvert.

8) Dredging

Dredging affects both the nature and diversity of the flow conditions and disturbs the development of habitats. Measures to address this pressure include ceasing dredging or reducing the intensity and timing of dredging. Ceasing dredging may have an impact on flood risk and may not be acceptable in all cases. Ceasing dredging creates the conditions under which a more natural range of flow conditions can be established but these conditions may take many years to develop. The time period required to re-establish more natural conditions depends upon the extent and amount of the dredging and the nature of the river. Where the supply of sediment is large in comparison with the dredged volumes then natural conditions may be re-established quickly but where the supply of sediment is small then re-establishment of natural conditions may require periods of time measured in decades.

Reducing the intensity of dredging does little to address the pressure, as the diversity of flow conditions and the periodic disturbance to the habitat still continues. Reducing the frequency of dredging may not significantly affect the diversity of the flow but the reduced frequency of disturbance of the system may bring some ecological benefits.

9) Impounding

Impoundments have the potential to have a wide range of effects by:

a) interrupting connectivity between upstream and downstream
b) modifying flow regimes downstream,
c) preventing the downstream movement of sediment and hence causing substrate modification downstream

The lack of connectivity can have a major impact, particularly on fish migration. The modified flow regime and bed substrate downstream may affect macrophytes and invertebrates. Potential measures to mitigate these pressures include:

a) the removal of the dam or weir. Where the impoundment is providing storage this may not be acceptable.

b) construction of fish passes to provide connectivity. This improves connectivity by allowing the movement of target species of fish but does not address the other impacts of the pressure.
c) allow the passage of sediment downstream. This is often difficult to do under gravity alone. If a system involving trapping sediment and transporting it is used then this is often costly to implement.
d) establish a more natural flow regime downstream. By controlling releases of water downstream it may be possible to mitigate the impact that large impoundments have on modifying the natural flow regime. The extent that this can be done depends upon a number of factors including: the purpose of the impoundment, the incoming flow regime and the amount of storage relative to the volume of inflow.

10) Constriction

The pressure arises from constrictions to the flow arising from artificial structures such as weirs or bridges. These influence the range of flow depths and velocities experienced and so affect the nature of habitats. The impact of such pressures may be small but in the case of low major bridges the impact can approach that of culverts. The impact of weirs can in some cases be minor but in major cases can approach the impact of an impoundment.

In many cases the removal of the structure is not practical but in some cases the structure may be modified to reduce its impact. The cost of doing this may in some circumstances be high.

11) Intensive land use

This pressure arises from intensive use in the riparian zone. This can lead to high levels of nutrients entering the river and high sediment concentrations. This can directly affect macrophytes, invertebrates and fish populations. Large sediment loads entering the river can alter the nature of the bed sediments which can also have an in-direct affect on these populations. The pressure can be removed by adopting less intensive land use practises. Other measures include:

a) the provision of buffer zones adjacent to the water body which act to intercept nutrients and sediments
b) modify vegetation management adjacent to the water body
c) develop the connectivity between the river and the floodplain

Brunet et al (1994) have shown that the narrow riparian strip immediately adjacent to the river channel may be of paramount importance in terms of geomorphological processes. Riparian zones appear to play a major role in sediment retention (Schlosser and Karr, 1981; Cooper et al, 1987 and Brunet et al, 1994). Natural river margins consist of a complex mosaic of patches that vary in elevation, soil type and inundation frequency and duration. These patches form the habitats for a wide range of floodplain communities. As a result restoration of the floodplain as part of the river ecosystem can be very complex due to the complexity of the processes.

The timescale for natural recovery of floodplain systems may be long. Bayley (1991) suggests that restoration of the river floodplain and the hydrological regime of most large, temperate systems might take upwards of 100 years of sustained effort. Brookes (1995) considers that improvements can be achieved in timescales varying from 1 to 150 years.

From an ecological standpoint floodplain restoration activities can be grouped into five general types:

a) restoration of riparian strips (Brunet et al, 1994, Peterson et al, 1987)

b) intensive restoration of relatively small but ecologically very valuable patches (Galat and Rasmussen, 1995)
c) less intensive restoration of larger floodplain areas (Sparks et al, 1990)
d) restoring the original hydrograph (Bayley, 1991) and
e) relaxing constraints on lateral river channel migration so that natural processes recreate a mixture of floodplain features (Palmer, 1976).

Brookes et al (1996) point out that, in the context of floodplain restoration and rehabilitation, 'many questions remain unanswered and it is clear that the science of floodplain restoration is very much in its infancy and hindered by a dearth of scientific data. The very limited experience of large-scale physical restoration to date has shown the enormous costs and uncertainties involved with flood plain restoration (National Research Council,1992).

12) Removal of natural barriers

This pressure arises as the result of removal of naturally occurring barriers such as woody debris or log jams or the removal of barriers to connectivity such as naturally occurring waterfalls or rock formations.

Such features as woody debris or log jams provide valuable habitat, particularly for invertebrates, and their removal removes those habitats (Shields and Smith, 1992). The measure to address this pressure is to cease removal of these barriers. This may have or be perceived to have flood control implications. During major floods woody debris and log jams may be swept downstream and may cause channel blockage and flooding. This perceived danger can lead to pressure to remove such features.

The removal of naturally occurring barriers such as waterfalls or rock formations may lead to significant morphological pressures upstream and downstream. The measure to address this pressure is not to remove such barriers.

13) Modifications to sediment regime

This pressure may arise from a number of causes. Land use change may affect the sediment yield from a catchment or the movement of sediment within a catchment may be affected by river channel management, for example, the construction of sediment traps. Channel modifications may also affect sediment movement and hence the sediment regime. The impact of land use change may be reduced by improving sediment management throughout the catchment through land-use management. Measures can also be taken to reduce erosion in the riparian zone. If management throughout the catchment cannot be implemented then buffer zones adjacent to water bodies can be introduced to reduce the impact on the water bodies.

Brookes et al (1996) believe that any significant reduction in sediment loading is likely to take decades and may be unattainable.

14) Measures within urban areas

Within many urban situations measures must be implemented within a very constrained corridor. Such restrictions mean that a full range of wildlife habitats, restoration and landscaping may not be possible (Ellis and House, 1994). Rehabilitation to a pre-disturbance state may, therefore, be unattainable in many urban situations.

15) Construction/structures

The presence of constructions or structures may modify the flow and, in the case of transitional and coastal waters, the wave conditions. This can have a major impact on habitats and hence ecology. In the case of embankments and piers the natural substrate may also be removed. The mitigation options include removal of the structure or its replacement with a more natural solution (soft engineering). In the case of embankments in tidally dominated areas these may be breached or a spillway provided to reduce the impact on water movement.

16) Catchment or coastal cell perspective

The WFD characterisation is based on discrete water bodies. The pressures on each water body and the risk has been assessed that these pressures are such that the water body may not achieve GES. In the above measures have been described that potentially could be used to assess particular pressures. There is a risk that this will encourage too narrow a perspective in the assessment of potential measures. It may be that the most appropriate approach would be to consider mitigation strategies within the context of the natural system, for example, on a catchment basis for rivers and lochs or in the context of a coastal cell for coastal water bodies. This approach would be preferable to addressing individual pressures water body by water body. It is recommended that the assessment of potential mitigation measures is carried out within a catchment or coastal cell context rather than by addressing issues water body by water body.

This suggests that the approach that should be adopted is that the pressures should be reviewed within the natural unit be it catchment or coastal cell. The pressures need to be understood within this context and within the natural processes of the system before mitigation measures are formulated on a water body by water body basis.

4.1.4 Measures for abstractions

Introduction

Abstractions take place from rivers and lochs for a variety of uses. By removing water from the river or loch this modifies the flow regime which can impact on the ecology. Factors which affect the potential impact of abstractions include the quantity of water removed, the seasonality of abstractions and whether and where the water is ultimately returned to the water system. In general, the greatest pressures arise when water is abstracted during periods of low flows. If water the same volume of water is abstracted during high flow periods then the proportional impact is often less. In some cases, water that is abstracted is returned to the water body after use. In some cases this does not happen.

Potential measures

There is a range of potential measures that can be considered to mitigate the impact of abstractions.

Alternative sources: water can be obtained from other sources which are not as sensitive to abstraction. This, in general, is often expensive and in many cases is not feasible. The practicality and cost of doing this is very case dependent.

Demand management: there is a range of options available for demand management. The overall demand may be reduced by conservation measures based on using water more efficiently. Water users can be encouraged to provide local storage so that water need only be abstracted during high flow periods when the impact of abstraction is likely to be less.

Return flows: where abstracted water is returned to a water body after use, the return of water as close as possible to the point of abstraction can be encouraged. This is likely to reduce the length of water body affected by the abstraction and may reduce the potential ecological impact of the abstraction.

Nature of abstractions

Tables 4.5 and 4.6 give a breakdown of industries and the number of potential water bodies affected. Those water bodies that are at risk of failing to achieve GES on hydro-morphological grounds as a result of abstractions were selected. Heavily Modified or Artificial Water Bodies were excluded from consideration. The resulting water bodies were then broken down by the industry associated with the abstraction.

Table 4.5 Number of rivers affected by abstractions broken down by industry

Industry	**Rivers**	
	Number	**%**
Beverage industry	12	1.7
Distillery	126	18.3
Fish Farm	47	6.8
Food processing	2	0.3
Golf course	15	2.2
Horticulture	3	0.4
Hydropower	113	16.4
Mining	5	0.7
Navigation	10	1.4
Paper and pulp	7	1.0
Power generation: non hydro	3	0.4
Private water supply	2	0.3
Public water supply	332	48.1
Water supply other	13	1.9
Total	690	100.0

Table 4.6 Number of lochs affected by abstractions broken down by industry

Industry	Lochs	
	Number	**%**
Beverage industry	1	0.4
Distillery	36	14.4
Fish farm	36	14.4
Food processing	2	0.8
Golf course	9	3.6
Horticulture	1	0.4
Hydropower	12	4.8
Mining	16	6.4
Navigation	4	1.6
Paper and pulp	4	1.6
Power generation: non-hydro	2	0.8
Public water supply	107	42.8
Water supply other	20	8.0
Total	250	100.0

4.1.5 Discussion of feasibility of measures to remove or mitigate abstraction pressures

The feasibility of measures to mitigate or remove abstraction pressures depends significantly on the particular circumstances of the abstraction. In general, the mitigation or replacement of abstractions for water supply and hydropower is both difficult and expensive. From the Tables above, however, it can be seen that hydropower and water supply between them account for approximately 67% and 56% of the rivers and lochs, respectively, affected by abstractions.

Those industries in which measures are likely to be more easily applied such as Horticulture and Golf courses account for only approximately 3% and 4% of the rivers and lochs, respectively, affected by abstractions.

The conclusion would appear to be that it is unlikely to be feasible to mitigate or remove a significant number of the abstraction pressures in the short-term. A significant percentage of the water bodies at risk of failing to achieve GES as a result of abstractions are associated with either Hydropower or Water Supply

4.1.6 Uncertainty of whether the identified measures will lead to the achievement of good ecological status

As indicated above one cannot have complete confidence that the identified measures will lead to the required improvements in hydro-morphology or that the changes in hydro-morphology will provide the required improvement in the ecological status of the water body.

If the identified measures do not provide the required improvement in the ecological status then it may be necessary to carry out additional work at additional cost. The implications of this uncertainty on the estimation of costs are discussed below.

4.2 Literature review of scientific evidence for the impact of potential measures

Recent work (Janes *et al*., 2004) has shown that scientific evidence on how well restoration projects and associated techniques have performed is limited; a point also noted by other authors that comment that substantive quantitative analysis is limited (see for example Brookes 1996; Friberg *et al*., 1998 and more recently Harrison *et al*., 2004). Post project assessments that extend over timescales long enough for river restoration outcomes to fully develop, (i.e. outside the normal funding/PhD period of 3 years) appear to be even rarer (Downs and Kondolf, 2002). Evidence for the necessity of such longer-term monitoring was noted at a very recent '10 years on' site meeting at the River Cole demonstration project (Coleshill, Nr Swindon) where the restoration work was perceived as entering a 'new phase' (Richard Vivash *pers comm.,* Feb 2005). There has also been discussion about the focus of projects (i.e. too biological Champoux *et al*., 2003 or not geomorphological enough Clarke *et al*., 2003) perhaps to the detriment of sound scientific analysis of overall project success and, as stated by Ormerod (2004), interdisciplinary collaboration is very rare for a subject, paradoxically, with such cross-disciplinary interest.

That said, the aim here is not to denigrate the value of reach-scale and site specific river restoration but instead to point out that there is an urgent requirement for scientifically sound post-project appraisal and it would be unwise to assume that all restoration projects that focus on, for example, installing pool-riffle sequences into a section of a watercourse will have immediate benefits for a specific reach. Furthermore, now may be an appropriate time to consider specific restoration and enhancement projects in the context of catchment scale issues and start to recognise that, whilst it may difficult to demonstrate the ecological benefit of the installation of one pool and riffle sequence (see Harrison *et al*., 2004 for example), their individual value might be better viewed in the context of having potential benefit for the whole catchment. This notion is further discussed by Bannister *et al.,* 2005 (available on the RRC website in the next few months) and is backed up by various papers (e.g. Sear 1994, Poole et al. 1997 and Harper *et al*., 1998).

In fact most of the discussion surrounding the value of river restoration stems from a range of design manuals (see Table 4.7) and text books mostly related to either geomorphological principles (see Sear *et al.,* 2004 for details of these) or ecological status (Boon., *et al* 1992). Whilst such information is valuable in terms of aiding design, pure scientific evidence which shows the success of river restoration projects at the reach scale and their sustainability over the longer-term remains limited.

A few examples do, however, exist. The following is a reflection of the various view points of these papers.

River substrate manipulation

The review found no scientific papers specifically on the removal of artificial bed materials. A more detailed search might reveal information pertaining to this aspect since, for example, it is known that some undergraduate/MSc dissertations (e.g. Hulbert, 2004) have concentrated on this aspect but their findings are not readily available in the public domain and results may not necessarily be scientifically robust.

Similarly, evidence is surprisingly lacking with regards to gravel augmentation such as the implementation of riffle sequences although Emery *et al.,* (2003) extol the virtues of using a classification technique to evaluate river 'patchiness' in terms of hydraulic performance of features such as pool and riffles but also state that it is essential that it is in comparison with other aspects such as the physical chemical and biological elements that 'physical biotopes' can be successfully characterised.

Harper *et al*., (1998) is one example where the relationship between river form and hydraulics has been compared to biological status after restoration work noting that shallow riffles with high flow velocities resulted in richness of functional habitats not found elsewhere and yet pool sequences equally have their own unique species diversity. What is clear from these papers and others (e.g. Gregory and Gurnell, 1994; Thompson, 2000, Orr and Carling, 2000 etc) is that precise geomorphological 'first principles' must be adhered to during construction of riffles and it must be acknowledge that by the very dynamic nature of river processes and organism life cycle there is always likely to be a level of uncertainty in their performance. Similarly, appraisal techniques used for fisheries improvements where riffles and pools are discussed (e.g. Pretty *et al*. 2003; Hendry *et al*. 2003; Pasternack *et al*. 2004) remain difficult to quantify.

Bed and bank reinforcement

Limited evidence was also identified regarding bed and bank reinforcement techniques. A number of papers do, however, exist on the general role of vegetation for bank protection and its effectiveness (Rowntree and Dollar, 1999; Mannsbart, and Christopher, 1997; Thorne *et al*., 1998; Anderson *et al*., 2004) although these are not specifically related to river restoration. The results however, are not conclusive in their outcomes and there remains much discussion about when, and for how long, they are effective. For example, Rowntree and Dollar (1999) noted that dense growth of willow were found to have a resistance equating to banks with a silt-clay ration of 70% and although they appeared to increase bank stability in the short term, it remained unclear how sustainable these were over the longer term since their very existence changed the flow characteristics of the river.

River re-sectioning / River straightening /River realignment /River channelisation

A few papers discuss restoring meanders, with particular emphasis on meander parameters and empirical relationships for use in meander restoration. Rinaldi and Johnson (1997a) and Rinaldi and Johnson (1997b) for example both discuss the accuracy of empirical relations of meander parameters for use in restoration procedures, identifying the dangers and inappropriateness of using simple regression equations for restoration design, particularly in specific cases (e.g. unstable and under disturbed basin conditions). One of the few general papers found on river re-meandering was Kronvang et al. (1998) which outlines the monitoring outcomes of re-meandering on the rivers Brede, Cole and Skerne, identifying a change in morphology in terms of the total diversity and the type of features recorded post-project.

In terms of diversifying flow, papers were identified on generic deflectors and on riffle and pool techniques. Biron *et al*., (2004) for example focuses on the effects of altering the angle, height, and contraction ratio of deflectors in terms of the impact on bed morphology and potential for bank erosion around the technique, for informing the design of the structures. Deflectors oriented at 45° were shown to have the least potential for bank erosion, whereas both 90° and 135° structures would require additional bank protection. Where bank scour is not of particular concern, a 90° deflector design in fish habitat restoration projects was suggested to maximize scour hole size.

Pretty *et al.*, (2003) focuses on assessing the benefit of in-stream structures, identifying in many cases, that the addition of flow deflectors in low-gradient rivers has a minimal effect on fish assemblages, suggesting the possibility of concentrating on the development of lateral and off-channel habitats within the river corridor as an alternative.

Culvert Removal

It is generally recognised that the removal of culverts should have a benefit for river ecology and natural process. The issue of culvert removal has generally however, had a higher profile in the United States. Whilst some of these projects have been well documented (see especially Pinkham 2000), the discussion tends to relate to the specific difficulties associated with deculverting rather than providing any scientific evidence about their success. Similarly the River Restoration Centre's manual of techniques (Vivash and Janes 2002) provides an example of how to deculvert a river, but again scientific success is not included.

Dredging

Numerous papers exist on the effects of dredging although most focus on coastal scenarios. A few papers were found on the effects of dredging on macroinvertebrates (Koeli & Stevenson, 2002) and macrophytes (Lubke *et al*,. 1984) in rivers yet these papers are not directly related to river restoration techniques. Koeli and Stevenson (2002) for example looked at the effects of dredging on macroinvertebrates and found taxa densities to be highest at sites that have never received dredged material, suggesting the need for its strategic placement and specifically avoiding islands or other areas where macroinvertebrate diversity would naturally be relatively high. Lubke et al. (1984) also noted the negative impact of dredging, but on vegetation, suggesting that a long period of time will elapse before plant communities return to their original condition following dredging.

Flow Manipulation

A few papers were found on flow manipulation/restoration. Arthington and Pusey (2003a) provide a number of examples used in Australia to restore river flow regimes but mainly focus on issues such as, how much water a river needs and how this can be maintained through better water allocation between users. The paper concludes with the need for changes in policy to ensure higher levels of water allocation for the environment. Conversely, a number of papers exist on the importance and effects of flow on river biology especially with respect to fish population dynamics. Arthington et al (2003b) for example looks at the environmental flow requirements of fish in rivers using the DRIFT (Downstream Response to Imposed Flow Transformations) methodology but focus on the effectiveness of the tool rather than the method findings. Tharme (2003) also discusses tools for environmental flow assessment providing an overview of global environmental flow methodologies. Brown & Ford (2002) however, evaluate the importance of flow regime on the success of fish species, concluding that the flow regime is an important determinant of the reproductive success of fishes in regulated rivers, stressing flow manipulation as a powerful tool for managing fish species. These texts however, once again do not directly relate to restoration projects although they can no doubt help to inform restoration techniques.

Impoundment and Constriction

A wide range of articles have tackled the issues related to the effects of dams on fish access and the impacts these have in terms of decline of native species (e.g. Gehrke et al. 2002; Taylor et al. 2001) whilst Graf (2003); Gore & Hamilton, (1996); Fjellheim & Raddum, (1996) for example have looked at geomorphological impacts flow and river ecology of dams and weirs.

Yet despite the clear signals of the disruption of structures to watercourse the evaluation of impoundment removal remains almost non-existent.

Intensive use (buffer zones/ bank removal)

The potential benefits of buffer zones are often discussed but no direct evidence was found that related the introduction of buffer zones to rivers or embankment removal to restoration projects. Papers were, however, found on the importance of floodplain connection to rivers (Ward *et al*,. 1999; Pringle, 2003) but surprisingly none on the effectiveness of re-connecting floodplains to rivers. No scientific papers were specifically found on flood storage although the use of wetlands for natural flood storage is well documented (e.g. Morris *et al*,. 2000).

Removal of natural barriers

Interestingly no papers were found about the removal of natural barriers yet conversely and, encouragingly in terms of habitat diversity issues, there is a growing body of literature that stresses the importance of maintaining woody debris in rivers (e.g. Lehane *et al*,. 2002; Brooks *et al*., 2004).

Modifications to sediment regime

Whilst there is a large body of geomorphological literature that discusses issues such as the geomorphological implications related to sediment starvation associated and gravel extraction (e.g. Sear and Archer 1998; Sear *et al*., 2004; Billi *et al*., 1992; Thorne *et al.,* 1997)) the effects of modifying the sediment regime in terms of improving watercourses is limited with most references (as discussed above) that do exist, concentrating on the specific effects of installing riffle type features.

Summary

- Scientific literature that specifically looks at changes that have occurred as a result of restoration practices in an integrated fashion are limited as is timescale.
- Monitoring (certainly in England) often tend instead to be completed on a piecemeal basis as part of the Environment Agency’s routine programmes and hence do not necessarily relate to the initial restoration objectives.
- At present restoration of a reach or section of watercourse cannot necessarily guarantee immediate ecological improvements especially when completed in isolation without taking account of other contributing catchment scale processes.
- There is a need to continue to restore appropriate habitat conditions however, especially under the requirements of the Water Framework Directive, but emphasis must be put on including appropriate monitoring to help inform future success.

Table 4.7 Selected design manuals and text books relating to river restoration

Name o f Manual	No of case studies	Applicability to UK rivers	Indication of success	Types of techniques
River Restoration Manual of Techniques Vivash and Janes 1999; 2002)	17	yes	subsequent performance - subjective	soft-eng / natural regeneration / river restoration
The New Rivers and Wildlife Handbook Ward, Holmes and Jose (1994)	41	yes	Partially through case studies	soft-engineering / natural regeneration
A Rehabilitation Manual for Australian Streams Volume 1 & 2 Rutherford et al (2000)	in body of text	Some aspects	Appraisal techniques discussed	soft-eng / natural regeneration / river rehabilitation
Stream Corridor Restoration Manual ~ U.S. Principles, Processes and Practices FISRWG (1998)	in body of text	Some aspects	Appraisal techniques discussed	river restoration / habitat enhancement
Applied River Morphology Rosgen (1996)	unknown	unknown	not evident	soft-eng / natural regeneration / river rehabilitation
River Channel Restoration: Guiding Principles for Sustainable Projects *Brookes and Shields (1996)*	6 (plus some in text)	yes	not evident	soft-eng / natural regeneration / river rehabilitation
Wetland Restoration Manual Bardsley et al (2001)	9 (part 1)	yes (wetlands mostly)	not evident	habitat restoration / rehabilitation
Waterway Bank Protection: a guide to erosion assessment and management EA (1999)	in body of text	yes	not evident	non-engineering/engineering solutions
Riparian Land Management Technical Guidelines Volume 1 & 2 Lovett and Price (2002)	in body of text	unknown	not evident	riparian management/river rehabilitation
Channel Restoration Design for Meandering Rivers Soar and Thorne (2001)	1	yes	not evident	river engineering methods/river restoration
Design manual on river and channel revetments Escarameia (1998)	none	yes	N/A	river engineering methods/river restoration

Manual for the Hydraulic Design of Side Weirs May *et al*., (2003)	none	yes	N/A	river engineering methods
River Diversions: Design Guide Fisher and Ramsbottom (2001)	none	yes	N/A	river engineering/restoration
Managing river habitats for fisheries Soulsby (2001)	in body of text	yes	Partially	soft-eng / natural regeneration / river rehabilitation
Guidelines for rehabilitation and management of floodplains - ecology and safety combined Summers *et al*., (1996)	2	yes	Yes - Attention points for design	river rehabilitation
Habitat Enhancement Initiative (HEI) : Farming & Watercourse Management Handbook Wood-Gee (1998)	in body of text	yes	not evident	non-engineering/engineering solutions
Daylighting: New life for buried streams Pinkman (2000)	19	unknown	challenges/lessons	river restoration/engineering
Upper Kennet Rehabilitation Project - Technical CD Thames Water (2004)	1	yes	Lessons & benefits	soft-eng / natural regeneration / river rehabilitation
Restoration of Riverine Salmon Habitats: A Guidance Manual (Fisheries technical manual 4) Bird (1997)	in body of text	yes	Critical evaluation of techniques	habitat restoration / rehabilitation
Restoration of Riverine Trout Habitats - A Guidance Manual Summers et al (1996)	in body of text	yes	Drawbacks/effectiveness	habitat restoration / rehabilitation
River Crossings and migratory fish: Design Guidance (Part 3 design) Boyack and Robertson (2000)	none	yes	not evident	non-engineering/engineering solutions
Handbook for assessment of hydraulic performance of environmental channels - Report SR490 HR Wallingford (2001)	in body of text	yes	worked examples	non-engineering/engineering solutions
A Wild Trout Trust Guide to Improving Trout Streams Holloway *et al*., 2002)	7	yes	Advantages and Disadvantages	river restoration / habitat enhancement
River Training Techniques Fundamentals, Design and Applications Przedwojski *et al*., (1995)	none	unknown	not evident	non-engineering/engineering solutions
Urban Stream Repair Practices - Center for Watershed Projection Washington (Shueler & Brown, 2004)	31	Some aspects	Some details	Whole range for river restoration to bank protection
Restoration of Aquatic Ecosystems NRC(1992)	13	unknown	not evident	restoration/rehabilitation

4.3 Field verification of measures to address identified pressures

The identification of appropriate measures to address the hydro-morphological pressures was carried out as a desk exercise based on knowledge and experience. It was considered prudent that the suitability of the identified measures should be checked by carrying out a limited number of field visits to identify whether the proposed measures where indeed appropriate.

In January 2005 a number of field visits were undertaken. These were restricted to river water bodies as these represent the majority of water bodies considered to be at risk of failing to achieve GES due to hydro-morphological pressures. Within this class however, sites were selected so that a wide range of river types were visited.

A detailed account of the site visits is given in Appendix 1. The main conclusion was that the identified measures were indeed appropriate to address the identified pressures. This gave confidence in the contents of Table 2.1. The visits did bring into question, however, whether the original characterisation of some of the water bodies as being as risk of failing was correct. The visits suggested that when water bodies are investigated in greater detail it may be that some of those currently considered to be at risk of failing to achieve GES will be found to be at GES.

The site visits were limited to sites that had been characterised as being at risk of failing. Thus no sites which are currently considered to be at GES were visited. It is thus not possible to comment on whether there are some sites that are currently considered to be at GES but which when considered in greater detail will be found to be failing to achieve GES.

4.4 Time scales for achieving ecological impact

It may take time for the required hydro-morphological improvement to take place following implementation of the measures. This will depend upon the nature of the pressure and the selected measure. There may be a trade-off between cost and the speed of achieving the morphological improvement. Thus the fastest option could be achieved by carrying out works which would, upon completion, fully restore the reach to a natural state but this might be costly. A slower option might be to remove the pressure and then wait while natural processes restore the reach to a natural state. This would be slower but less costly. In the latter case the timescale for achieving the required hydro-morphological improvement will depend upon the timescale associated with the hydro-morphological processes.

Once the hydro-morphological improvement has been achieved it may take some time to achieve the required improvements in ecological status. In this case the timescale will be determined by the ecological processes at work.

The timescale for hydro-morphological improvement will depend upon a number of factors including the nature of the river. High energy rivers are more likely to adapt to change more rapidly than low energy systems. Depending upon the nature and severity of the pressure and the measures adopted, a low energy river may take decades to achieve the required hydro-morphological state. Thus the timescale associated with achieving the hydro-morphological improvement is more directly related to the nature of the water body then to the nature of the measures undertaken. It is thus not possible to directly associate timescales with all the proposed measures independently of the nature of the water body.

Work carried out for the EC funded URBEM project has shown that river rehabilitation work often takes of the order of 10 years from initial concept to implementation. It would be expected that it would take a further number of years before the ecological improvements are finally achieved.

5 DESCRIPTION OF POSSIBLE FUTURE SCENARIOS

5.1 Introduction

The context within which SEPA will have to operate for the work on hydro-morphology as part of the implementation of the WFD is not fixed at the present. For example it is not yet known what impact the changes to the Common Agricultural Policy (CAP) that are currently being implemented will have on the hydromorphological pressures. In addition the funding under Quality and Standards III has not yet been decided. Thus there are a range of scenarios concerning the external environment within which SEPA will have to operate.

In addition it may be sites will have to be prioritised in some way. At the moment it is not clear on what basis the sites should be prioritised.

5.2 Quality and Standards III

Quality and Standards III refers to the proposed investment plan for Scottish Water (SW) for the period 2006 to 2013/14. This identifies the works that need to be carried out in order to achieve good ecological status at those sites that are impacted by SW activities. At the moment it is not clear whether the hydro-morphological elements of Q and S III will be wholly or only partly funded. If it is only partly funded then SW will not have sufficient resources in the period up to 2014 to carry out the remaining work which has not been funded under Q and S III.

5.3 Common Agricultural Policy

The Agreement reached by Ministers in June 2003 on Reform of the Common Agricultural Policy (CAP) marks a significant change in European agricultural policy. It signals a move away from subsidies 'coupled' directly to commodity production towards 'de-coupled' support in the form of an annual Single Farm Payment based on the amount of subsidy received in the past rather than what farms produce from now on. At the regional level, the Agreement offers considerable flexibility in terms of the degree and nature of the de-coupling such that positive impacts can be enhanced and negative impacts mitigated.

Though the Agreement is in place, full details have yet to be provided on the exact funding available to Scotland and on how particular aspects of the Agreement are to be implemented. Given the radical nature of the change in policy, there is uncertainty on how farmers will respond. This means that there is uncertainty in the impact of the revised CAP will have on the hydro-morphological pressures currently affecting some of the water bodies.

In some cases, de-coupling may enhance the environment through, for example, reducing grazing pressures or the risk of water pollution. Many valued environmental features, however, require active land management, for example, through mixed grazing of cattle and sheep and de-coupling may lead to negative impacts. In some instances, extreme rationalisation of a sector into a few, very intensive production units could cause localised environmental problems. In this case there may be the potential for regulation in order to avoid significant environmental problems.

Within Scotland there has been some effort made to identify potential regional changes in agricultural practises. These suggest likely changes to agriculture and suggest that in some areas there may be reductions in hydro-morphological pressures on some water bodies but there may also be increases in pressures in other areas. These assessments are based on a regional scale and so cannot be used to predict potential changes to individual water bodies. In the light of these uncertainties it is too early to predict the precise impact of the reforms to the CAP on the hydro-morphological pressures.

The process of adjustment of farming practises to the revised CAP may take some time. Thus it may be some time before there are associated improvements in the ecological status of water bodies.

The impact of CAP reform on the hydro-morphology pressures will depend upon the nature of the pressure. The impact of CAP reform is likely to be largest on those pressures related to intensive agriculture. By affecting agricultural practises, it also has the potential to impact indirectly on other pressures such as ‘Modifications to sediment regime’. These indirect impacts are, however, likely to be small and likely to occur over a long time scale. For the purposes of this study, therefore, it has been assumed that the main impact of CAP reform will be on intensive agricultural practises. In order to assess the potential impact it has been assumed that the changes in agricultural practises will reduce the incidence of the pressure as expressed by the number of water bodies by some percentage. It has been assumed that the cost of treating the remaining water bodies is not affected.

5.4 Internal SEPA priorities

In the case that there are not sufficient funds to carry out all the works required to ensure that all water bodies meet the requirements of the WFD by 2015, it may prove necessary to prioritise the work. It is not clear how this will be done. One option might be that Designated Conservation Sites should be given priority. The reason for the designation, however, may be unrelated to the hydro-morphological pressure and addressing that pressure may not enhance the feature of the site that led to designation. Thus, for example, if a site has been designated for its bird population then this may be unaffected by improvements to the hydro-morphology.

Other possible approaches to prioritising sites include:
a. maximising the length of water body that is brought up to the appropriate morphological state
b. giving priority to those water bodies that are in socially deprived areas
c. concentrating on those water bodies where it is expected appropriate water quality standards will also be met

Restoration/Remediation Regulations

An important factor influencing the level of hydromorphological improvement that can be achieved by SEPA is the level of regulatory power it has relating to restoration and the timing of these powers.

At present Section 20 of the Water Environment and Water Services Act (Scotland) (WEWS) Regulation of Controlled activities gives SEPA powers to control , licence, serve works notices only for <u>new</u> engineering activities from 2005/06, it is not retrospective and so does not give SEPA the power to address works that have been carried out in the past.

Section 22 of WEWS covers restoration/remediation measures and states that:
The Scottish Ministers may by regulations make such provision for or in connection with remedial or restoration measures as they consider necessary or expedient for the purposes of facilitating the achievement of the environmental objectives set out in river basin management plans (RBMPs).

In this section "remedial or restoration measures" means the carrying out of any operations or works, or the taking of any other action, in relation to any land or body of water with a view to-
a) remedying or mitigating the effects of any pollution (as defined in WEWS Section 20(6)) of the water environment
b) improving or restoring the characteristics of any body of water.

This implies:
a) that SEPA cannot implement any measures under Section 22 (e.g. serve notices or carry out improvements on behalf of others) until after the agreement of the RBMP objectives (2009/10) which in many cases will be too late to achieve required improvements by 2015
b) improvements relate to “bodies of water” which limits the level of site/reach specific improvement that can be achieved.

The problem of SEPA only being able to implement powers under Section 22 until after the agreement of RBMPs may be overcome if SEPA were granted the powers to implement measures prior to the agreement of the RBMPs. At the moment it is not clear whether or not the granting of powers to SEPA to implement measures prior to the agreement of the RBMPs will be brought forward to 2006. If SEPA is granted such powers in 2006 then there will be more time before 2015 for SEPA to bring forward schemes, which may mean that it will be easier to achieve some of the hydromorphological targets by 2015 than if powers are granted later. If SEPA has to wait until the agreement of the RBMPs then until the granting of those powers SEPA will have to rely more on persuasion and advice to achieve the WFD targets. This will thus affect the strategy that SEPA will have to adopt.

6 POTENTIAL APPROACHES TO SETTING TARGETS AND MEASURING THE DEGREE OF HABITAT IMPROVEMENT

6.1 Introduction

To implement the requirements of the WFD there is a need to set targets for hydro-morphological improvements and to put in place a system for measuring the degree of habitat improvement. The philosophy that has been adopted is that as far as possible existing methods and approaches should be adapted to satisfy the requirements of the WFD implementation rather than develop new methods specifically for this purpose. Thus we believe that the recommended approach should be compatible with acceptable practises elsewhere, providing that these are based on sound science or subject to testing.

The assessment of habitat is based upon the belief that the habitat sets the context for biological communities and that physical habitat sets the framework for ecological systems. There are a number of methods that have been developed to assess the physical and geomorphological condition of streams and have the potential to enhance the interpretation of biological assessments of stream condition.

Methods such as the Geomorphic River Styles are based on an assessment of the geomorphic character of the river or stream. It compares the contemporary stream character and behaviour with the conditions expected in undisturbed conditions and predicts the future river character based on extrapolation from contemporary behaviour. The method is based on the direct relationship between types of biota and geomorphic units. At the moment it would appear that this relationship has not been established in a Scottish context. Rosgen produced a river classification system that classifies rivers into categories on the basis of their geomorphological features. These are based on un-modified, natural river systems. It is not clear how the method could be extended to systems that are subject to anthropomorphic pressures. There has been no attempt to link these to Rosgen classes to habitat quality and so the link between the geomorphology and the habitat quality has not been established..

Methods which directly address the physical nature of the habitat include the method developed for the US EPA called HABSCORE and the River Habitat Survey (RHS). They are based on the assumption that the quality and quantity of available physical habitat has a direct influence on the biotic community.

The HABSCORE method is based on scoring a number of physical factors which characterise the micro and macro scale stream habitat. RHS measures variables that represent the character of stream habitats, with the assumption that these variables reflect the geomorphological processes that are acting to form those habitats. Habitat Quality Assessment (HQA) provides an indication of the diversity of valued features present within the river, banks and riparian zones. As such, on its own, it is not a proven indicator of lack of departure from naturalness (a WFD need). Habitat Modification Scores/Indices (HMS/I) do provide a clear measure of departure from naturalness. As such, HMS can be used to aid in the quantification of damage done to a river system, but would not necessarily be ideal as a target to set for improvement unless combined with other features of river systems.

Methods such as RIVPACS (Wright et al, 1984, Moss et al, 1987) are based on the connection between the macroinvertebrate community and the habitat and water quality of a site. It is not clear whether such methods encompass all the potential physical influences on macroinvertebrate communities. Within the context of the WFD there is a disturbing circularity in this approach. The aim is to assess the ecology of the water body. In order to achieve this one considers the nature of the habitats but one assesses the habitats by assessing the macroinvertebrate community.

The existing assessment methods have been developed for specific purposes and the methods thus reflect those objectives. The use of biological or geomorphologically based parameters also depends upon one's confidence in the present understanding of the linkage between the ecology and geomorphology of water bodies. In selecting an appropriate approach it is necessary for SEPA to examine the use to which it will be put and secondly the confidence that they have of the present understanding of the linkage between ecology and geomorphology for water bodies in Scotland.

At present the understanding of the linkages between ecology and geomorphology for water bodies within Scotland does not seem to be sufficient to support methods which concentrate on geomorphology, such as Geomorphic River Styles or Rosgen. Meanwhile there is not the evidence to suggest that methods which rely upon detailed surveys of biological communities, such as RIVPACS, include a sufficiently detailed description of the physical influences. This would tend to support the use of methods which address the physical nature of the habitats, such as HABSCORE and RHS.

Within the context of hydro-morphology one concern is whether the nature of the flow and the substrate departs from what would be expected under 'natural' conditions.

A recently approved CEN standard on river hydromorphology (EN 14614) has been developed to enable surveys of rivers to be carried out using a common set of features in Europe, and used for WFD assessments. The RHS method conforms to the standard.

Work is now in progress to produce a follow-up CEN standard on quality assessment of river reaches based on ten groups of river attributes. These are listed below.

1. Channel geometry
2. Substrates
3. Channel vegetation and Organic debris
4. Erosion/ deposition character
5. Flow
6. Longitudinal continuity as affected by artificial structures – effects on migratory biota
7. Bank structure and modifications
8.Vegetation type/structure on banks and adjacent land
9.Adjacent land-use and associated features
10. Degree of (a) lateral connectivity of river and floodplain; (b) lateral movement of river channel

Protocols on assessing quality on a five point scale for each of the above have been drafted, tested and are out for consultation and further testing and refinements. Two examples are illustrated below to identify how quantitative or qualitative assessments can be made depending on the availability of information.

This system, using the qualitative assessment method, may offer good potential for use by SEPA based on expert judgements of its own staff and experts who SEPA may consult for advice. The first requirement is to determine the existing quality band, and then set targets for improvements that would be required to improve the waterbody to good ecological status, or help it achieve its maximum ecological potential if it has been designated a HMWB.

	Attributes assessed	**Score band A – Quantitative**	**Score band B – Qualitative**
1. Channel geometry	**1a: Planform** (reach-based) **1b: Channel section (long and cross)** (use site and other data and combine for whole reach)	1 = 0-5% planform change. 2 = >5-15% planform change. 3 = >15-35% planform change. 4 = >35-75% planform change. 5 = >75% planform change.	1 = Near-natural planform. 2 = Partial – moderate planform changes. 3 = Moderate – extensive planform changes. 4 = Planform changed in majority of reach. 5 = Reach completely, or almost completely, straightened. ☠ 1 = Near-natural. 3 = Moderately altered. 5 = Greatly altered. *If no data for 1b, the score for Channel geometry is 1a by itself. Keep two elements separate; take worse case.*
6. Longitudinal continuity as affected by artificial structures – effects on migratory biota	Reach-based and local impacts of sluices and weirs on ability of biota (e.g. migratory fish) to travel through reach, and sediment to be transported naturally	Quantitative methods unlikely to be possible.	1 = No structures. 2 = Structures present, but having no or only minor effects on migratory biota and sediment transport. 3 = Structures having moderate effects on passage of migratory biota and sediment transport. 4 = Structures that allow passage for some species but NOT sediment. 5 = Structures are barriers to all species and to sediment.

6.2 An existing approach to setting targets for rivers – River Habitat Objectives

The River Habitat Objectives (RHOs) are based on the premise that improvements in river habitats will produce ecological benefits. Through implementation and monitoring, it should be possible to refine knowledge of this relationship under different environmental conditions.

RHOs aim to:

Describe the quality of river habitats;
Characterise river habitats, and impacts affecting them;
Offer a diagnostic tool for identifying problems;

Improve management decisions to protect and enhance river habitats;
Provide a framework for identifying and prioritising river habitat improvements;
Provide a means for detecting change and measuring the impacts of management.
Stage 2 of the RHO process is the "Collation and Assessment of Habitat Condition". Stage 2a: is collation of Non-RHS data, and Stage 2b is collation of RHS data (if available). This should equate to, or be compared with, the provisional assessments based on expert judgements that have been carried out so far (i.e. fail, at risk etc.).

Stage 2a includes gathering data on:

- Land-use/landscape character;
- Population density;
- Water quality;
- Flood Zones, Flood Defence Assets and Maintenance;
- Waste disposal sites;
- Fisheries management;
- Recreation uses;
- Water resource use;
- Major in-stream structures;
- Upstream and downstream impacts;
- Wildlife conservation designations.

In Stage 2b, waterbodies within which RHS has been carried out, the data can be used to verify the existing morphological conditions suggested by Stage 2a assessments. If no RHS has been undertaken the RHS database can be used to establish, with reasonable confidence, what the overall character of the reach might be, given certain geological and land-use scenarios. Slope, distance from source, height of source and site altitude are used by the RHS database to cluster RHS sample sites for so-called "context analysis". This approach can be used to assess the likely habitat conditions within a reach based on the character of sample sites representing this group at a regional or national scale.

Assessment is undertaken in five steps, with step 3 only carried out when there are reliable RHS data from sites surveyed within the reach.

Step one: context analysis. This is to make sure that quality assessment can be determined for sites of a similar character. Habitat Modification Scores (HMS); Habitat Quality Assessment Scores (HQA), and Morphological Indices values (derived from assessments of substrate, flow, channel activity and channel vegetation), can then be used in future stages of the process in a comparative way with confidence. (HMS enables an insight into how far a waterbody departs from naturalness, based on data derived from RHS sites within the water body).

Step two: land-use classes. Which one of four 'land-use groups' are represented? The RHS database can be used to do this. Relationships between habitat condition and land-use mean that predictions can be made about the likely habitat quality in reaches where RHS site data are not available.

Step three: where RHS site data exist within the waterbody, these are analysed to help characterise the existing habitat conditions in terms of HMS, HQA and Morphological Indices. Comparison can then be made, using the context analysis, to determine how the observed habitat conditions compare with those of other sites of similar 'type'.

Step four: setting a provisional General Habitat Quality Score (**GHQ) for the waterbody**. This is done using the HMS and HQA data from either the RHS site data, or where RHS data are NOT available within the reach, the average results from the context analysis.

Step five: setting confidence limits for the RHS analysis. This is based on the frequency and distribution of RHS samples within the reach (the more there are, the greater the confidence). It also involves consultation with local people with knowledge of the catchment to ensure that conclusions drawn from all other sources are consistent with theirs.

Deciding what to aim for (ie habitat quality to enable GES or MEP to be reached) – i.e. setting targets

Setting well-informed habitat objectives requires a good information base.The aim should be to restore the character of the river to as close to a natural state as possible. The extent to which this will be possible will be determined by many factors, not least socio-economic ones. The use of RHS cluster analysis provides a means of determining what habitat character a river is likely to have when in Good Ecological Status. Under the WFD this should be the target for rivers not designated as HMWB; if so designated, their hydromorphology should be restored to as much as possible to enable the waterbody to reach Good Ecological Potential.

Stage 4 of the RHO process is 'Options Appraisal' (i.e. what measures need to be taken to allow recovery), is not the subject of this exercise (at the present time). However it should be noted that if the reach is deemed to be currently of high habitat status (GHQ class A), this may equate to 'good' or 'high' ecological status under the WFD, and therefore demand a high level of protection not to deteriorate.

As the RHO approach is only in the process of being tested (on the Tweed), caution is required in expecting it to be the panacea to setting targets, and then monitoring progress in achieving targets. It offers very strong possibilities for water bodies and catchments where limited or non-existent data exist on the physical character of rivers and floodplains. In such cases data available from remote sensing, on national databases and GIS can be used in the first instance for setting targets prior to the necessary data gathering that will be required to verify and substantiate the real hydromorphological status of river catchments.

6.3 Setting realistic targets

SEPA should be setting targets for:

- all HMWBs to have hydromorphological characteristics which enable the biology to reach its maximum ecological potential;
- all other water bodies that are not in 'High status' to have hydromorphological characteristics that enable the biological indicators to be retained at, or restored to, good ecological status;
- retain near pristine hydromorphology of waterbodies designated as being in high status.

In reality, the initial status assessments for some waterbodies will be based on limited information, and for others on good and reliable data. The first stage in target-setting should be:

- to have a clear and defensible assessment of the hydromorphology of all waterbodies.

For designated HMWBs, the reasons for being so designated need to be stated, as does the extent to which the whole waterbody is affected. For all other water bodies not in high or good status, the hydromorphological modifications that contribute to the biology not being in high or good status also need to be identified, as does their extent (e.g. floodbanks affecting 40% of the waterbody; bank armouring along 25% of banks; extensive presence of fishery groynes; impounding weirs etc.)

Targets for improvement can only be set based on either national targets for changes in status (see above), or local targets for individual waterbodies and catchments based on what needs to change to enable the waterbodies to achieve good ecological status or maximum ecological potential.

The second stage in target-setting is, therefore:

- to identify on a reach by reach basis what modifications need to be removed, reversed or mitigated against.

For HMWBs, it is likely that for many reaches the structural changes that have occurred in the past will need to be retained, so mitigation works in the form of river rehabilitation will be required. In some cases it may be possible to modify the structures to reduce their ecological impact, or partially remove some elements. Whatever is needed to restore the maximum potential biological functioning of the waterbody should be the target.

For all other waterbodies not already in good or high status, the targets need to be to remove all, or the majority, of the physical modifications that are perceived to be impacting the biology, and contributing to the biological elements of the WFD status assessment not being in good status. This may require a whole host of possible options, including removal of floodbanks or flood protection works, restoration of more natural banks or riparian zones, re-connecting floodplain and river hydrological connectivity, or channel rehabilitation/restoration.

Decisions will need to be taken that clearly identify what the priorities are, and how much of a waterbody is required to be reaching its maximum ecological potential or reaching good status. The biological indicators will need to drive the programme of measures to reach hydromorphological targets, as the target should not necessarily be to remove/change all physically impacted reaches within a waterbody, but to remove the impacts that are limiting the biology.

6.4 Existing approaches to monitoring habitat improvements

The River Habitat Survey (RHS) is a method for assessing the physical character and quality of river habitats: it has been developed to help the conservation and restoration of wildlife habitats along rivers and their floodplains. The RHS could be used both before and after a programme of measures are put in place.

To assess how natural the character of the features present are, that is, are they the ones that one would expect for a water body of its type, the RHS database can be used. RHS has so far not been readily used for monitoring habitat improvement other than by noting changes to the physical character of a river after works carried out. Changes in the Habitat Modification Score (HMS) could be used as a simple measure to express changes.

As RHS is the existing UK method for recording physical habitats and characteristics of rivers, banks, riparian zones and floodplain it is recommended that it should be attempted to be used in the first instance. It may be too crude a tool to be used on its own for monitoring changes brought about by programmes of measures, and determining if targets are met. In many cases it may suffice, especially if combined with additional site-specific appraisals linked to site-specific problems that required addressing. The advantage is that it provides a national database for recording, and comparing changes.

6.5 Assessing if Measures have been successful

RHS is required unless assessment of achievement is based simply on visual observations relating to the changes to the 'pressures' identified as being responsible for a river not being of Good Ecological Status (i.e. floodbank/revetment/flow manipulation structures removed)…..i.e. common sense observations of the 'pressure' addressed rather than the resultant habitat change. .

If the RHO approach is adopted, the easiest way to measure habitat change that should bring biological gains would be to note a change in River Habitat Quality scores that would be anticipated/predicted prior to carrying out the programme of measures. This offers a quantifiable target for the action. However, any other desirable outcomes from the suggested habitat improvements that may not necessarily produce a change in RHQ class, but may nonetheless be measured in some way, should also be recorded (e.g. socio-economics, amenity, landscape etc.).

The table below illustrates examples of generic types of improvement, suggested works and measurable outcomes from where the current habitat condition is improved from RHQ Class E (from a draft information leaflet describing the RHO process).

Table 6.1 Generic types of improvement, suggested actions and measurable outcomes

Type of Improvement	Suggested Action	Indicative RHO outcome
1. Flood defence structures abandoned or removed	Natural recovery, assisted by initial structural works	Initially to D (but may improve further over time)
2. Proactive work to counter the effects of overgrazing (recovery of riparian zone)	Livestock exclusion via fencing and/or planting	D
3. Rehabilitation works to mimic natural channel form in a heavily modified channel	Rehabilitation of channel form	D
4. Reduction of impact from flood defences for agricultural land	Removal of lesser engineering works (embankments)	C
5. Alternative route for path/roadway affecting a reduction of impact	Removal of major engineering works (e.g. culvert)	B
6. Full restoration of river form and processes	Major river restoration scheme – reinstatement of original river character	A

Geo-RHS is more comprehensive than RHS on its own, but, like RHOs, is still in the process of being refined, and has never been used so far as a monitoring or post-project appraisal tool. It is probable that Geo-RHS would be appropriate to use where the target has been to restore hydromorphological processes to a waterbody. As this is the next stage in the UK's development of attempting to understand river processes, it should be an appropriate tool to use where measures have been put in place to assist natural stream recovery.

If a waterbody has been identified as being geomorphically sensitive, and restoration of its functioning is the target, more sophisticated monitoring may be required. In addition to following up on a fluvial audit, professional geomorphologists will be needed appraise the success of changes brought about by measures taken. This is not likely to be needed in all cases, and geographers or biologists should be able to be trained to carry out post-project appraisals that include an assessment of the geomorphic functioning of the waterbody. Elements of Rosgen, Styles etc. could be incorporated, but it will be essential to link such monitoring to the proposed SEPA river typology that is at present being developed.

Although it may appear too simplistic, it is essential that simply inspecting (by visual means) if the causes of failure to meet good status have been reversed is included as part of the monitoring protocol. The same applies to determining the extent to which programmes of measures have addressed problems associated with HMWB and the waterbody is now able to meet it maximum ecological potential.

Whatever system of monitoring is used (even walk-over observational methods) it will be essential to include provision for accurately recording the findings on a database, developing standard recording methods, and implementing a QA process that will help deliver consistency throughout SEPA, and vary little according to individuals involved. This system is in place for RHS, but not for other potential methods.

6.6 Setting target improvements for lochs

There is a need to consider a method for lochs. As for rivers, there would be advantages if such a method could be based on an existing method or approach and there are a number of existing approaches to lake monitoring. Some of the earliest of these arose out of the 1972 US Federal Clean Water Act. As a result of this the US Environment Protection Agency developed the Environmental Monitoring Assessment Program and produced the Field Operations Manual for Lakes (FOWL). The FOWL provides protocols and sampling strategies for a comprehensive range of biological water quality and hydromorphological parameters.

When the Water Framework Directive (WFD) was being developed there was no equivalent European based assessment approach for lakes. As discussed above, in the late 1990s, however, the River Habitat Survey method had been developed by the Environment Agency a strategic tool for surveying and analysing river habitat quality (Raven 1998). With the advent of the WFD it was clear that there would be advantages in having an equivalent of the RHS but for lakes that could be used to characterise and assess the physical habitat of lakes and reservoirs. Accordingly a Lake Habitat Survey (LHS) has been developed (SNIFFER, 2004). It has been designed with the requirements of the WFD in mind and so it can be used for condition monitoring of sites as well as providing a systematic approach to environmental impact assessment and supporting restoration programmes for degraded lake eco-systems.

The LHS system is based on a combination of a small number of detailed plot observations along with a collection of whole-lake metrics. The LHS was designed specifically to provide a tool for:

- recording and assessing the hydromorphological characteristics of lakes,
- for the effective monitoring of the hydromorphological quality elements of lakes and
- assessing significant impacts on lake hydromorphology. . . .

The LHS methodology is still being developed and tested but it is expected that it will shortly provide the equivalent for lakes of the RHS. Thus the monitoring of habitat improvements for lochs could be based on the LHS in a similar way that RHS could be used as a basis for rivers.

6.7 Setting target improvements for Transitional and Coastal Waters

In transitional and coastal waters there is no equivalent to the system of River Habitat Survey applied to rivers. The existing classification systems applied by SEPA in transitional and coastal waters, primarily focus on the achievement of water quality objectives and ensuring biological quality is not impaired. The closest existing regime is probably the setting of conservation objectives for European Marine Sites, under Regulation 33 of the Habitats Regulations. These objectives define favourable conditions for the features of interest. For example, the favourable conditions of habitat features are defined in terms of quantity and quality of key habitats.

However, the relationship between favourable condition and good ecological status is unclear and few water bodies have such conservation objectives in place. This approach, therefore, doesn’t lend itself for use in the WFD.

Over the past decade, there has been increasing recognition of the potential physical impacts of development activity in transitional and coastal waters and the need to assess such changes at a systems level. In the field of flood and coast defence, the jointly funded EA/Defra Flood and Coast Defence Research Programme has undertaken a number of major research studies to seek to develop tools for estuaries through the Estuaries Research Programme (ERP). This study has made a major contribution to the understanding of estuary processes and geomorphology and developed methods for the assessment of physical impacts of developments. While the project has helped to clarify the links between physical modification and estuary processes and morphology, the implications for ecological quality remain poorly understood.

There is a need to develop monitoring tools that can detect changes in ecological elements related to hydromorphological modifications. Such tools should therefore, as a minimum, be able to assess and be sensitive to:

- Changes between types of ecological element within a water body e.g. angiosperms to benthic invertebrates;
- Changes in extent (absolute abundance) of ecological elements within a water body (angiosperms, macroalgae, benthic invertebrates);
- Changes in composition and abundance of all ecological elements within a water body.

For rivers, the River Habitat Survey (RHS) provides some of this functionality. While RHS has been applied to some parts of estuaries, coverage is patchy and the methodology would require significant development for effective application to transitional and coastal waters (Geodata Institute, 2000)[1].

For the time being any assessment of the ecological consequences of physical modification will necessarily have to rely on expert judgement and recognise that the science base on which such judgement might be based is limited. In additional, assessing the level of certainty in whether the intervention is working long-term wills b difficult. Stakeholders are unlikely to assist/accept the implementation of an improvement scheme will out a high level o detailed scientific evidence. Put simply, the key questions will be:

- Is there a need for the scheme?
- Will it work?

There are a number of uncertainties about achieving Good Ecological Status.

- Quality aspect reasonably well understood
- Quantitative aspect. Unclear how incorporated. Could be a key driver of improvement requirements

There is also uncertainty about what can be delivered by measures in terms of their effectiveness. In particular, there is uncertainty about cost-effectiveness of individual measures. Unit costs of measures, for example, are only part of the equation. There is a need to know quality of individual measures required for water body, the extent of pressures in the water body and the effect on ecological status. This may be achieved through a site-specific assessment.

7 COSTS OF ACHIEVING RESTORATION TARGETS AND MEASURING DEGREE OF HABITAT IMPROVEMENT

7.1 Assessment of unit costs for measures for hydro-morphological improvement

7.1.1 Introduction

For each of the identified methods a 'unit-cost' was estimated based on the experience of the team members and the published data. For some measures the cost is related to the length or area affected, for example, restoring channels that have been straightened and in these cases the unit cost was the cost per unit of length or area. In other cases, for example, fish passes, the cost of the measure is not related to the size of the water body but is a single cost.

The estimates of the costs represent the best assessment of an average cost for such work taking into account the potential size of river and the length affected. In reality the costs for particular locations will be subject to wide variations depending upon the particular circumstances. The estimated cost reflects an estimate of the average cost averaged over a large number of sites. Thus the unit costs should not be used to assess the costs for individual schemes.

Where a number of measures may be used to address a particular pressure an assessment has been made of the relative mix of different types of work based on experience and published data.

[1] Geodata Institute, 2000. The Development of a River Habitat Survey Methodology for Tidal River Sections. Final Report to SNIFFER No SR (00) 07F

The costing data came from a number of sources, including data from the RRC archive and data from individual schemes of which members of the project team had knowledge. Additional information was obtained from CEH et al (2003), Environment Agency (1998, 2002, 2004), RPA et al (2004), UKMPG/BPA report (2004). To apply this information a number of assumptions had to be made and these are discussed below.

7.1.2 Rivers

Data on a range of river schemes was collected and a sample is presented in Appendix 2. This data was derived from the River Restoration Centre database on schemes that have been carried out in the past. An attempt has been made to bring all the costs to a common basis representing present day prices. Care has to be taken in interpreting the cost of particular schemes as the cost of any scheme is a function of the size of the river and the particular circumstances of the scheme. Thus the cost of a particular scheme may not be a good indication of the average cost of such work.

One major factor in the cost of river schemes is the context of the river. The cost of carrying out river work in an urban context normally far exceeds the cost of carrying out work in a rural context. In urban rivers there are also commonly much stronger constraints on what types of work can be carried out.

The unit cost of many measures depends upon the size of the river with the cost being less for smaller rivers and possibly substantially greater for large rivers. When considering unit costs for this project a ‘typical’ Scottish river was considered. In particular cases the true cost will vary depending upon the size of the river. The unit costs used in this study for the proposed measures are shown in Table 7.1. The costs exclude the cost of any studies or design work that might be required.

7.1.3 Landclaim

Landclaim is probably the single most important pressure due to the direct removal of ecosystem elements resulting in significant losses to intertidal habitats (e.g. sandflats, mudflats and saltmarsh. However, because of the historical linkage between landclaim and the system’s sedimentary, morphodynamic and biological processes, it is difficult to quantify the precise magnitude of the present day impact. What is clear is that reclamation has resulted in a significant reduction in area and the biological integrity of the associated ecological elements, thus reducing the capacity to support many benthic, birds and fish populations. It was assumed, therefore, that its spatial extent is indicative of the amount of restoration required to achieve good to moderate status (the minimum target required).

Table 7.1 Table of unit costs for measures to address pressures for rivers and lochs

Pressure	Cost (£) per metre or single cost	Is Single Cost?
(blank)	**0.0**	No
Dredging - unspecified	**38.5**	No
Construction / Structures - embankments	**30.0**	No
Reinforcement - Unspecified	**500.0**	No
Resectioning - bank	**12.5**	No
Channelisation/realingment/straightening - straightening	**550.0**	No
Culverting - unspecified	**1,250.0**	No
Impounding - weir / dam	**200,000.0**	Yes
Channelisation/realingment/straightening - realignment	**550.0**	No
Reinforcement - concrete	**1,075.0**	No
Culverting - culvert / impassable	**1,250.0**	No
Channelisation/realingment/straightening - channelisation	**550.0**	No
Reinforcement - brick / laid stone	**1,075.0**	No
Channelisation/realingment/straightening - unspecified	**550.0**	No
Reinforcement - gabion baskets	**1,075.0**	No
Resectioning - unspecified	**12.5**	No
Intensive use - poaching	**82.5**	No
Construction / Structures - flood relief channels	**550.0**	No
Construction / Structures - flood walls	**550.0**	No
Intensive use - grazing	**82.5**	No
Construction / Structures - major bridges	**2,000,000.0**	Yes
Intensive use - management of riparian vegetation	**82.5**	No
Dredging - resulting in removal of sediment	**66.0**	No
Impounding - unspecified	**100,000.0**	Yes
Intensive use - unspecified	**82.5**	No
Intensive use - cultivating / planting to the bank	**82.5**	No
Culverting - culvert / passable	**600.0**	No
Modifications to sediment regime	**150.0**	No
Construction / Structures - on-line ponds	**30.0**	No
Reinforcement - other (carpets, tyres etc)	**1,075.0**	No
Resectioning - bed	**12.5**	No
Manipulation of sediment transport	**150.0**	No
Flow Manipulation - deflectors	**60.0**	Yes
Reinforcement - rip rap	**1,075.0**	No
Substrate manipulation / gravel addition or removal	**150.0**	No
Reinforcement - builders waste	**1,075.0**	No
Flow Manipulation - unspecified	**60.0**	No
Construction / Structures - unspecified	**30.0**	No
Flow Manipulation - boulder placement	**60.0**	No
Flow Manipulation - fords	**60.0**	Yes
Impounding - sluice	**100,000.0**	Yes
Construction / Structures - minor bridges	**200,000.0**	Yes
No activity detailed	**0.0**	No

Under the UKTAG guidance for risk assessment pressures and threshold criteria for TraC waters <15% landclaim is indicative of the morphological boundary between good and moderate status. Achieving this target will require the removal and subsequent restoration of landclaim unless it can be demonstrated to do so would not be cost effective and result in unreasonable negative impacts on its designated use. To estimate cost of landclaim restoration the following assumptions were considered:

- Land will have to be purchased
- Existing sea defence will need to be taken down
- Design costs (8% of project costs) are required to develop land reclaim and habitat restoration schemes
- If higher ground is not an option for further urban development landward of the scheme then new defences will have to be established
- Measures to implement and prepare land for suitable habitat restoration will be required
- Monitoring of habitat restoration will need to be developed and implemented

Using information from the EA's framework for setback schemes (unpublished) estimates from 8 different projects within the Humber estuary were reviewed (site sizes ranged from 96 ha to 369 ha). Each site had been assessed for land reclaim and subsequent habitat restoration works. Given the assumptions listed above it is estimated that the cost for restoring landclaim will range from 24k to 68k per ha, with an average cost of 40k per ha. Note that the smallest project was not always the cheapest.

However, to calculate the cost implications for the present project, information on the extent of landclaim was unavailable. Previous information on agricultural and industrial landclaim areas provided in a GIS format provided insufficient coverage and was not available for all water bodies. To overcome this limitation OS 1:50000 maps were used to estimate landclaim based on extent of urban development fringing the water body boundary. Estimates were divided into the following four categories.

- <25%
- 25-50%
- 50-75%
- 75-100%

These estimates only represent a proportion of the water body boundary (length) affected by landclaim. Information on the extent of the landclaim landwards was limited and so it was assumed that because the objective is to restore land back to an appropriate estuarine and/or coastal habitat, the dimensions of a typical or range of setback schemes was used to estimate the landward extent of reclaim (Table 7.2).

The dimensions used to calculate cost estimates were based on the widths of schemes listed in Table 7.3:

- Low: 200m
- Moderate: 710m
- High: 2000m

Table 7.2 Summary of restoration schemes and dimensions

Scheme	Width dimension	Reference
Orplands Seawall managed retreat	200m	HR Wallingford (1994) Orplands seawall, river Blackwater, Essex: Hydrodynamic assessment of proposed managed retreat. Report EX 3019
Abborts Hall saltmarsh managed retreat	350m	Dixon et al (1997) Habitat creation opportunities for landward coastal realignment: Essex case studies. CIWEM, London
Tollesbury saltmarsh managed realignment	400m	Boorman et al (1997) Largescale experimental managed realinment Vol 1: At Tollesbury, Essex
Thorngumbald Managed Realignment	600m	ABPmer Ltd. (2003) Thorngumbald Managed Realignment - Creek Modelling Report 1009.
Alkborough Managed Realignment	2000m	ABPmer (2004) Alkborough Managed Realignment, Phase 2 Regional Modelling Studies. R1090.

Scheme widths were used in conjunction with estimated landclaim length for each water body. Note that the water body length (m) is the perimeter of the water body polygon and not the total distance of shoreline. A considerable amount of time would be required to recalculate the shoreline lengths of each water body and was outside the scope of this project. This value will overestimate landclaim estimates was the distance across the mouth of each water body will also be included.

The following calculations for each water body were conducted.

1 $$\text{Length of landclaim (m)} = \frac{\text{\% Landclaim estimate}}{100} \quad \text{WB length (m)}$$

2 $$\text{Length of restoration (m)} = \frac{\text{Calculation 1}}{100} \quad 15$$

3 $$\text{Calculation 1} \quad \text{Calculation 2}$$

4 $$\text{Area of restoration (m}^2\text{)} = \text{Calculation 3} \quad \text{Average scheme width (m}^2\text{)}$$

The final costs of restoration for each water body were based on estimated managed retreat widths (low, moderate and high) and cost estimates for planning and implementing such as scheme (low, moderate and high). These estimates were then assessed against the four categories for estimated length of shoreline affected by landclaim (<25%, 25-50%, 50-75% and 75-100%) For <25%, the low range was considered 15% (the UKTAG criteria for good to moderate status) as each water body had failed on morphological grounds and thus designated as potentially heavily modified.

7.1.4 Dredging

From an ecological perspective ceasing to dredge navigation channels may be an appropriate restoration/mitigation option, but estimating a cost associated with this is difficult to ascertain.

For the purpose of this study, it was considered that this option is not feasible since the cost of closing ports would result in navigation channels for shipping becoming unusable. For example, to close and relocate the Port of Goole, Humber Estuary, it is estimated to cost £137 million (capital and operating) and this is without taking into consideration the economic and social impacts if closure were to occur (Freeman et al., 2004). Ceasing dredging from a purely operational perspective, however, would have to consider the cost of keeping a dredged channel open for large vessels. In this case, it is estimated to be £10,000 per km.

Mitigation measures that related to beneficial use and reduced dredging intensity/timing may have positive cost implications where there is no change to navigation. However, for beneficial use this is generally off set by the cost to transport and/or transfer material to designated areas. For reduction of dredging intensity and timing, cost estimate have not been proposed as these are difficult to translate into cost per unit length/area and so have not be included in the final cost analysis.

7.1.5 Lagoons and basins

In England and Wales, lagoons and basins are considered separate to transitional waters. However, for the purposes of this study and in the absence of data on the nature of the pressure associated with each of these transitional water bodies, it has been assumed that the corresponding % estimate of landclaim associated with the water body in which the lagoon is attached will be used to reflect the amount of potential land reclaim requiring restoration. For example, Island Farm Lagoon (Firth of Forth) is associated with the Middle Forth Estuary water body, which has an estimated 50-75 % landclaim. Consequently, the lagoon will be assessed as having 50-75% landclaim.

7.1.6 Managed realignment

The shape of managed realignment schemes are infinite in design, thus is it assumed that the site is square in nature and so converting hectors to km is taken as the frontage along the estuary by square rooting 10,000m to give a frontage length of 100m.

7.2 Estimation of total costs for hydro-morphological improvement

The characterisation data provided by SEPA identifies the size of the water body, in terms of length, perimeter or area but it does not identify the proportion of the water body which has been morphologically altered. Thus the pressure on a river reach may be the presence of bank protection but it may not extend the entire length of the water body and so the mitigation measure may only have to be applied to a proportion of the length of the water body. Where practical, maps and GIS data are being used to assess the actual length that will need to be treated. In a large number of cases it will not be practical to assemble such data and an arbitrary assumption will have to be made as to the proportion of the water body that will have to be treated. Where there is no other data it has been assumed that the length of the water body that has to be treated is the minimum percentage as defined by the UK TAG for the water body to be considered to be at risk of failing to achieve GES. This raises the general issue as to whether when work is planned the entire length subject to the pressure will be treated so as to remove entirely that pressure or only a length that is sufficient to ensure that GES is achieved. In the latter case it may not be necessary to completely remove the pressure in order to achieve GES.

Table 7.3 Unit costs per restoration and mitigation option

Activity	Restoration/mitigation	Unit	Low	Mod	High
Channelisation/realignment/ straightening (unspecified)	Managed realignment	ha	£8,000	£30,000	£60,000
	Construction of breach/spillway	each	£1,500	£250,000	£500,000
	Re-connecting existing meanders to main channel	km	£10,000	£30,000	£40,000
	Footbridge construction	each	£6,000		£20,000
	Initiate natural platforms/meanders	km	£25,000	£40,000	£80,000
Construction/structures (embankments)	Managed realignment	ha	£8,000	£30,000	£60,000
	Construction of breach/spillway	each	£1,500	£250,000	£500,000
	Rehabilitation of floodplain	ha	£4,000	£25,000	£130,000
	Removal of structures e.g. weirs, bridges etc.	each	£25,000		£1,000,000
	Removal of hard engineering	km	£70,000	£80,000	£120,000
	Replacement with more natural solution (soft engineering structures)	km		£1,500	
	Reworking of slopes to form a more natural appearance	m^2		£750	
Construction/structures (jetties, piers)	Removal of structures	each		£1,000,000	
Construction/structures (unspecified)	Managed realignment	ha	£8,000	£30,000	£60,000
	Removal of structures	Each	£30,000	£250,000	£500,000
	Removal of hard engineering	km	£70,000	£80,000	£120,000
	Replacement with more natural solution (soft engineering structures)	km	£14,000	£27,000	£44,000
Dredging (deposition of dredged material)	Beneficial use	km		£11,000	
Dredging (resulting in removal of sediment)	Modify dredging regime and techniques	km		£66,000	
Dredging (unspecified)	Modify dredging regime and techniques	km		£66,000	
Flow manipulation (boulder placement)	Removal of sluices/weirs	Each	£10,000	£50,000	£160,000
Impounding (sluice/weir)	Build in fish passages	Each		£50,000	
	Improve existing fish passages	Each		£25,000	
Reinforcement (concrete/rip rap)	Removal of hard engineering	km	£70,000	£80,000	£120,000
	Replacement with more natural solution (soft engineering structures)	km	£14,000	£27,000	£44,000
Landclaim	See section 4.2.1	ha	£24,000	£40,000	£68,000

Where a water body is subject to a number of pressures then the costs for measures to address each pressure are calculated separately and then the costs for the water body aggregated.

The costs for each water body were then summed to determine the total cost.

7.3 Overview of costs for hydromorphological improvement

The details of the costs were prepared in spreadsheets that are associated with this report. For convenience the data is summarised here. Tables 7.4 and 7.5 show the water bodies summarised by morphological pressure. For each pressure Table 7.4 shows the total lengths of Rivers and lochs subject to that pressure and an estimate of the cost of addressing that pressure. In considering the table it should be remembered that water bodies may suffer from multiple pressures. It should be noted that the length gives the total length of water bodies affected by the identified pressure including HMWBs. As described above, the costs associated with HMWBs and those included within Q and S III have been excluded from this study. Thus the costs are the costs for treating those water bodies which are not HMWBs and are not included within Q and S III. Thus the costs are only for a proportion of the water bodies subject to the identified pressure. Table 7.4 gives the costs on the assumption that the entire length of the water body has to be treated. Table 7.5 gives the costs based on the assumption that the length of the water body that has to be treated is the minimum consistent with the fact that the water body was assessed as being at risk, as defined by the UK TAG guidance. Tables 7.6 and 7.7 give the corresponding figures for Transitional and Coastal Waters.

Table 7.4 Summary of costs for River and Lochs based on the full length of the water body affected

Activity	Length (km)			Cost (£)		
	Rivers	Lochs	Total	Rivers	Lochs	Total
(blank)	2,167	97	2,264	0	0	0
Dredging - unspecified	332	0	332	12,709,997	0	12,709,997
Construction / Structures - embankments	667	9.4	676	18,683,010	151,320	18,834,330
Reinforcement - Unspecified	342	29	371	133,464,000	14,336,000	147,800,000
Resectioning - bank	648	0	648	6,621,763	0	6,621,763
Channelisation/realingment/straightening - straightening	1,387	0	1,387	586,731,200	0	586,731,200
Culverting - unspecified	378	0	378	437,343,750	0	437,343,750
Impounding - weir / dam	2,930	1,573	4,503	31,200,000	4,400,000	35,600,000
Channelisation/realingment/straightening - realignment	193	0	193	79,277,000	0	79,277,000
Reinforcement - concrete	108	0	108	94,889,175	0	94,889,175
Culverting - culvert / impassable	222	0	222	122,588,750	0	122,588,750
Channelisation/realingment/straightening - channelisation	667	3.2	670	292,580,750	0	292,580,750
Reinforcement - brick / laid stone	118	0	118	104,508,275	0	104,508,275
Channelisation/realingment/straightening - unspecified	296	0	296	127,538,400	0	127,538,400
Reinforcement - gabion baskets	131	0	131	101,062,900	0	101,062,900
Resectioning - unspecified	240	0	240	2,697,775	0	2,697,775
Intensive use - poaching	164	0	164	13,514,820	0	13,514,820
Construction / Structures - flood relief channels	15	0	15	8,532,700	0	8,532,700
Construction / Structures - flood walls	126	0	126	62,176,950	0	62,176,950
Intensive use - grazing	255	5.7	261	18,438,090	467,115	18,905,205
Construction / Structures - major bridges	233	0	233	36,000,000	0	36,000,000
Intensive use – management of riparian vegetation	145	0	145	11,976,443	0	11,976,443
Dredging – resulting in removal of sediment	137	4.2	141	8,640,192	275,550	8,915,742
Impounding - unspecified	98	0	98	700,000	0	700,000
Intensive use - unspecified	80	0	80	6,637,290	0	6,637,290
Intensive use – cultivating / planting to the bank	1,826	288	2,114	125,523,420	21,530,355	147,053,775
Culverting - culvert / passable	55	0	55	18,294,600	0	18,294,600
Modifications to sediment regime	13	0	13	1,986,300	0	1,986,300
Construction / Structures - on-line ponds	144	0	144	3,812,790	0	3,812,790
Reinforcement - other (carpets, tyres etc)	442	0	442	0	0	0
Resectioning - bed	16	4.3	20	0	0	0
Manipulation of sediment transport	14	0	14	0	0	0
Flow Manipulation - deflectors	122	0	122	240	0	240
Reinforcement - rip rap	58	0	58	62,427,400	0	62,427,400
Substrate manipulation / gravel addition or removal	384	0	384	56,016,750	0	56,016,750
Reinforcement - builders waste	38	0	38	41,331,600	0	41,331,600
Flow Manipulation - unspecified	69	0	69	977,820	0	977,820
Construction / Structures - unspecified	158	8.7	166	4,731,420	262,530	4,993,950
Flow Manipulation - boulder placement	7.8	0	7.8	0	0	0
Flow Manipulation - fords	32	0	32	120	0	120
Impounding - sluice	15	216	230	300,000	900,000	1,200,000
Construction / Structures - minor bridges	11	0	11	200,000	0	200,000
No activity detailed	54	0	54	0	0	0
	15,537	2,238	17,775	2,634,115,690	42,322,870	2,676,438,560

Table 7.5 Summary of costs for River and Lochs based on the minimum length of the water body affected

Activity	Length (km)			Cost (£)		
	Rivers	Lochs	Total	Rivers	Lochs	Total
(blank)	2,167	97	2,264	0	0	0
Dredging - unspecified	332	0	332	1,905,300	0	1,905,300
Construction / Structures - embankments	667	9.4	676	2,802,452	22,698	2,825,150
Reinforcement - Unspecified	342	29	371	20,019,600	2,150,400	22,170,000
Resectioning - bank	648	0	648	993,264	0	993,264
Channelisation/realingment/straightening - straightening	1,387	0	1,387	88,009,680	0	88,009,680
Culverting - unspecified	379	0	379	65,601,563	0	65,601,563
Impounding - weir / dam	2,930	1,573	4,503	31,200,000	4,400,000	35,600,000
Channelisation/realingment/straightening - realignment	193	0	193	11,891,550	0	11,891,550
Reinforcement - concrete	108	0	108	14,233,376	0	14,233,376
Culverting - culvert / impassable	222	0	222	18,388,313	0	18,388,313
Channelisation/realingment/straightening - channelisation	667	3.2	670	43,887,113	0	43,887,113
Reinforcement - brick / laid stone	118	0	118	15,676,241	0	15,676,241
Channelisation/realingment/straightening - unspecified	296	0	296	19,130,760	0	19,130,760
Reinforcement - gabion baskets	131	0	131	15,159,435	0	15,159,435
Resectioning - unspecified	240	0	240	404,666	0	404,666
Intensive use - poaching	164	0	164	4,054,446	0	4,054,446
Construction / Structures - flood relief channels	16	0	16	1,279,905	0	1,279,905
Construction / Structures - flood walls	126	0	126	9,326,543	0	9,326,543
Intensive use - grazing	255	5.7	261	5,531,427	140,135	5,671,562
Construction / Structures - major bridges	233	0	233	36,000,000	0	36,000,000
Intensive use - management of riparian vegetation	145	0	145	3,592,933	0	3,592,933
Dredging - resulting in removal of sediment	137	4.2	141	1,296,029	41,333	1,337,362
Impounding - unspecified	98	0	98	700,000	0	700,000
Intensive use - unspecified	80	0	80	1,991,187	0	1,991,187
Intensive use - cultivating / planting to the bank	1,826	288	2,114	37,657,026	6,459,107	44,116,133
Culverting - culvert / passable	55	0	55	2,744,190	0	2,744,190
Modifications to sediment regime	13	0	13	297,945	0	297,945
Construction / Structures - on-line ponds	144	0	144	571,919	0	571,919
Reinforcement - other (carpets, tyres etc)	442	0	442	0	0	0
Resectioning - bed	16	4.3	20	0	0	0
Manipulation of sediment transport	14	0	14	0	0	0
Flow Manipulation - deflectors	122	0	122	240	0	240
Reinforcement - rip rap	58	0	58	9,364,110	0	9,364,110
Substrate manipulation / gravel addition or removal	384	0	384	8,402,513	0	8,402,513
Reinforcement - builders waste	38	0	38	6,199,740	0	6,199,740
Flow Manipulation - unspecified	69	0	69	146,673	0	146,673
Construction / Structures - unspecified	158	8.7	166	709,713	39,380	749,093
Flow Manipulation - boulder placement	7.8	0	7.8	0	0	0
Flow Manipulation - fords	32	0	32	120	0	120
Impounding - sluice	15	216	230	300,000	900,000	1,200,000
Construction / Structures - minor bridges	11	0	11	200,000	0	200,000
No activity detailed	54	0	54	0	0	0
	15,537	2,238	17,775	479,669,972	14,153,053	493,823,025

Table 7.6 Summary of costs for Transitional Waters

Summary of pressure per unit cost	Unit	Length per WB	Cost Transitional (£)		
Pressure			**High**	**Mid**	**Low**
Channelisation/realingment/straightening - unspecified	km	4,395	15,581	3,887	1,512
Construction / Structures - embankments	km	107	7,089	3,816	2,957
Construction / Structures - jetties, piers	km	90	n/a	3,895	n/a
Construction / Structures - unspecified	km	113	1,911	1,074	905
Dredging - resulting in removal of sediment	km	269,480	n/a	370,543	n/a
Dredging - deposition of dredged material	km	321,901	n/a	44,124	n/a
Dredging - unspecified	km	6,231	n/a	4,593	n/a
Flow Manipulation - boulder placement	km	4	1,045	273	51
Impounding - sluice/weir	km	0	0	0	0
Reinforcement - concrete/rip rap	km	114	2,872.6	1,547.5	595
Landclaim	km	1,255	104,316	31,299	6,769

Table 7.7 Summary of costs for Coastal Waters

Summary of pressure per unit cost	Unit	Length per WB	Cost Coastal (£)		
Pressure			**High**	**Mid**	**Low**
Channelisation/realingment/straightening - unspecified	km	0	0	0	0
Construction / Structures - embankments	km	0	0	0	0
Construction / Structures - jetties, piers	km	148,997	53,919	31,253	24,448
Construction / Structures – unspecified	km	179,168	87,478	75,758	61,856
Dredging - resulting in removal of sediment	km	657	n/a	198,000	n/a
Dredging - deposition of dredged material	km	2,814	n/a	45,000	n/a
Dredging – unspecified	km	0	0	0	0
Flow Manipulation - boulder placement	km	0	0	0	0
Impounding - sluice/weir	km	16,258	40,000	16,471	4,667
Reinforcement - concrete/rip rap	km	235,274	25,403	15,511	8,003
Landclaim	km	24,266,212	6,583,573,311,415	1,704,071,870,236	423,630,827,785

In addition to the morphological pressures, some of the water bodies are affected by abstractions and these are broken down by industry in Tables 7.8 and 7.9. The figures in the Tables include water bodies that are potentially HMWBs. As discussed above it is not possible to assess the cost of addressing the abstraction pressures on a generic basis and so detailed, site-specific studies are required to determine the costs. Tables 7.8 and 7.9, therefore, just give the number of water bodies affected. It can be seen that the industry associated with the largest number of water bodies considered to be at risk of failing to achieve GES due to abstraction is water supply. The three largest industries, water supply, hydropower and distilling are associated with more than 80% of the rivers that are considered to be at risk of failure.

For lochs, the three largest industries, water supply, distilling and fish farming which are associated with more than 70% of the lochs that are considered to be at risk of failure.

Table 7.8 Abstractions from rivers broken down by industry

Industry	Number	%
Beverage industry	12	1.7
Distillery	126	18.3
Fish Farm	47	6.8
Food processing	2	0.3
Golf course	15	2.2
Horticulture	3	0.4
Hydropower	113	16.4
Mining	5	0.7
Navigation	10	1.4
Paper and pulp	7	1.0
Power generation: non hydro	3	0.4
Private water supply	2	0.3
Public water supply	332	48.1
Water supply other	13	1.9
Total	690	100.0

Table 7.9 Abstractions from lochs broken down by industry

Industry	Number	%
Beverage industry	1	0.4
Distillery	36	14.4
Fish farm	36	14.4
Food processing	2	0.8
Golf course	9	3.6
Horticulture	1	0.4
Hydropower	12	4.8
Mining	16	6.4
Navigation	4	1.6
Paper and pulp	4	1.6
Power generation: non-hydro	2	0.8
Public water supply	107	42.8
Water supply other	20	8.0
Total	250	100.0

7.4 Uncertainty in cost estimation

There is always an uncertainty in estimating the unit cost for a measure. If this is represented just as a range of costs then there is a problem of knowing how to include this uncertainty in the final estimate of the total cost. It would be extremely pessimistic if one were to carry out the evaluation twice, once using the lowest cost in the range for each measure and once using the highest cost for each range.

7.5 Presentation of cost information

The cost information is reported separately by type of water body: rivers, lochs, transitional waters and coastal waters. This information is derived within a number of spreadsheets. Due to their size and complexity these cannot be reproduced on paper and are held separately in electronic format.

7.6 Costs for education and training

A number of the pressures that have been identified as having the potential to cause water bodies to fail to meet good ecological status arise from current agricultural practises, such as, intensive land use adjacent to the water body. It may be that the measures required to remove or mitigate these pressures will not have to be funded and carried out by SEPA but may be addressed by others, such as the local landowner. To achieve this, however, SEPA may need to embark on suitable programmes of education and training. If SEPA wish to adopt this approach then it is recommended that a suitable allowance should be made for the costs of providing suitable education and training programmes.

The importance of the issue of training and education is related to the issue, as discussed above, of the implementation of the Restoration and Remediation Regulations. If the proposed Restoration & Remediation Regulations are brought in sufficiently early then SEPA will be able to act more directly but if these only come into force after the RBMP is approved in 2009 then SEPA will need to continue to rely solely on voluntary approaches through promoting best practice via education programmes for the first basin planning cycle.

7.7 Costs for measuring degree of habitat improvement

Monitoring to show habitat improvements is essential, and more importantly there needs to be an element of biological monitoring to ensure the measures have been beneficial (NOTE: under the WFD GES does not in itself involve habitat quality assessment – the habitat quality has to be sufficient 'to support' the biological quality at GES. As habitat quality is likely to affect macrophytes, fish and invertebrates most, monitoring of these in representative sites is required (say 1 in 10)).

RHS is the standard tool for habitat survey and should be robust enough to note changes made through the programme of measures. The cost of suitable monitoring should represent a small proportion of the overall cost of programme of works required to address the hydro-morphological issues.

8 CONCLUSIONS

This project is concerned with the measures that will need to be taken for water bodies that are considered to be at risk of failing to achieve good ecological status or good ecological potential due to hydro-morphological pressures. The project process is summarised in Figure 8.1

For the hydro-morphological pressures that have been identified, the project has detailed potential measures that may be carried out to mitigate or remove these pressures. These measures have been assessed in terms of:

a their ability to reverse the pressure
b the potential for the measures to result in morphological change
c feasibility of carrying out the proposed measure

The literature review of the scientific evidence of the impact of the proposed measures showed that much of the scientific work that has been carried out relates measures to their impact on the river morphology while there are very few studies which relate measures to their impact on the ecology. For some measures there is scientific support for the impact on morphology but some measures have not been studied and so there is no underpinning scientific support. This may reflect the lack of research funding in the area rather than suggest that these measures are ineffective.

One could consider attempting to classify measures on the strength of their scientific basis but this might disfavour potentially useful measures which have not yet been subject to scientific assessment.

The proposed measures were reviewed during a series of field visits which showed that for those sites visited, the proposed measures were appropriate for the identified pressures. The field visits showed that some of the water bodies that have been identified as being subject to hydro-morphological pressures may still be achieving good ecological status.

Once measures have been carried out, in some systems there may be a significant period before the impact on the hydro-morphology is fully achieved. This delay may depend upon the nature of the measure and the nature of the water body. Once the hydro-morphological improvement has been achieved there may be a further delay before there are changes in the ecological system. Thus it may take a significant period of time after pressures have been removed or mitigated before good ecological status is achieved. As the time period required to achieve the required improvement in ecological status depends upon the characteristics of the water body as well as the nature of the measure, it is not possible to associate specific time scales with specific measures.

The context within which SEPA will have to operate for the work on hydro-morphology as part of the implementation of the WFD is not fixed at the present. For example it is not yet known what impact the changes to the Common Agricultural Policy (CAP) that are currently being implemented will have on the hydromorphological pressures. In addition the level of funding under Quality and Standards III has not yet been decided. Thus there are a range of scenarios concerning the external environment within which SEPA will have to operate.

A procedure has been developed for assessing the likely costs for implementing the measures. For each measure a 'unit' cost has been derived which is normally expressed as a cost per metre or per square metre. These unit costs have been derived from published data or the experience of project team members. The estimates of the costs represent the best assessment of an average cost for such work, taking into account the potential size of river and the length affected. The estimated cost reflects an estimate of the average cost averaged over a large number of sites. Thus the unit costs should not be used to assess the costs for individual schemes. Where a number of measures may be used to address a particular pressure an assessment has been made of the relative mix of different types of work based on experience and published data.

The costs for each water body were then summed to determine the total cost for each water body. This data is presented separately in a series of spreadsheets. The overall data has been summarised in a series of tables giving the lengths or areas of water bodies at risk and the associated costs of potential measures.

The issue of abstractions has also been considered. The industry which affects the largest number of water bodies is water supply. In the case of rivers the water supply, distilling and hydropower account for more than 80% of the water bodies affected while for lochs water supply, distilling and fish farming account for more than 70 % of the water bodies affected.

A number of the pressures that have been identified as having the potential to cause water bodies to fail to meet good ecological status arise from current agricultural practises, such as, intensive land use adjacent to the water body. It may be that the measures required the remove or mitigate these pressures will not have to be funded and carried out by SEPA but may be addressed by others, such as the local landowner. To achieve this, however, SEPA may need to embark on suitable programmes of education and training.

It may be that SEPA will need to consider the adoption and promotion of guidelines or Codes of Good Practise to encourage the desirable changes in land use practises. If SEPA wish to adopt this approach then it is recommended that a suitable allowance should be made for the costs of providing suitable education and training programmes or producing and promoting guidelines.

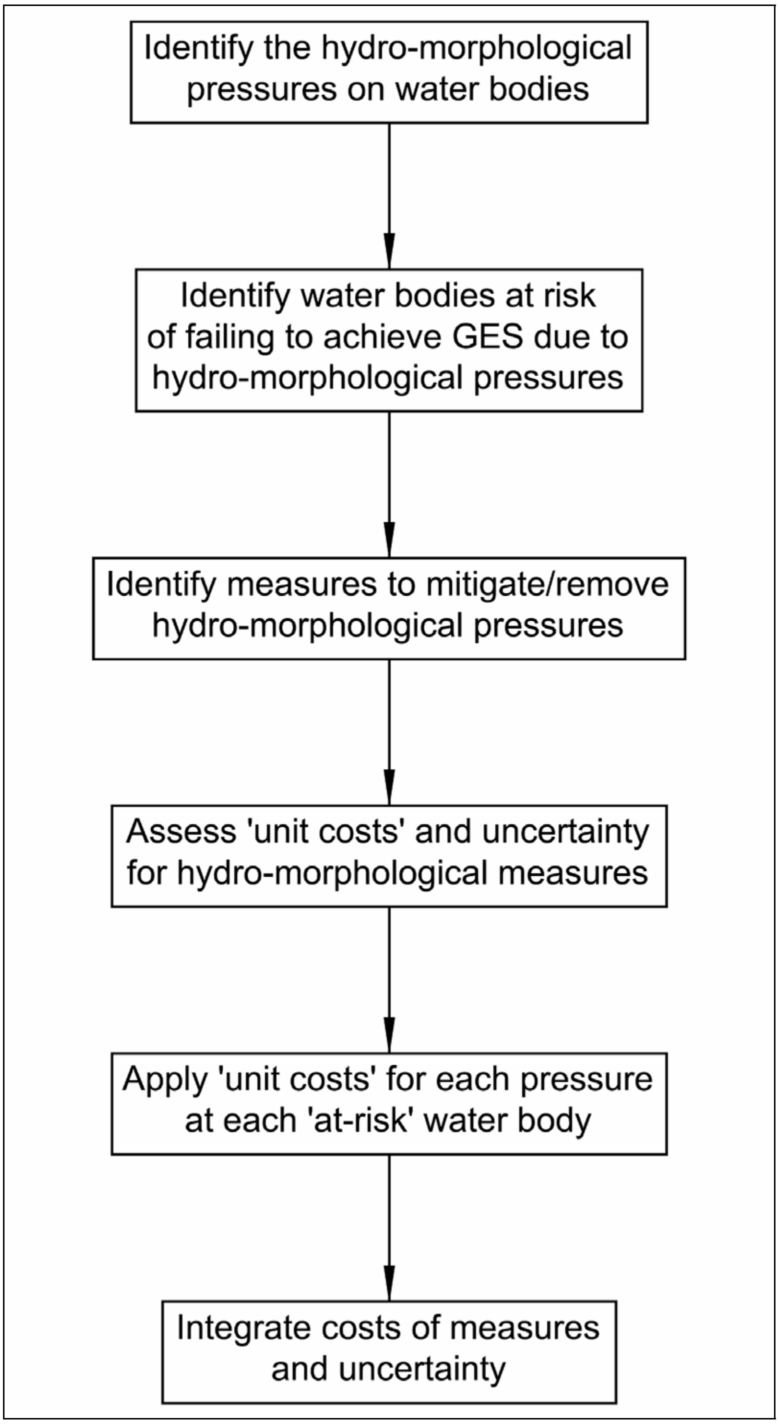

Figure 8.1 Flow chart for estimating costs of measures to address hydro-morphological pressures on surface water bodies

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APPENDICES

Appendix I Field validation of proposed measures to address pressures

CHANNELISATION - *RURAL*

ID 4726 Goodie Water (Site from which photographs taken – LAT 56 00 LONG 004 09 712

MORPHOLOGICAL DESCRIPTION
A straightened and deepened channel through the low-lying "Carse" that would have supported wet conditions. Low gradient and trapezoidal channel (6 metres wide). Little habitat diversity although willow and reeds line banks. Old meandering course of channel can be made out in adjacent fields.

DRIVING FORCE/ACTIVITY
Channel straightening/agriculture

PRESSURE
River straightening

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – too deep and turbid (Impact High)
Fish – limited spawning habitats (Impact High)
Benthic invertebrates – (Impact High)
Algae – slow flowing (?)

The reach should fail on Hydromorphological quality

RESPONSE/POSSIBLE MITIGATION TECHNIQUES
Re-meandering (one side) – feasible
Re-meandering (either side) – feasible and desirable
Re-design straight channel to sinuous multi-channel river – feasible and desirable
Restore channel – feasible and desirable
Reconnection of cut-off meanders – meanders infilled and only partial evidence of original location

APPROPRIATE MITIGATION AND RESTORATION
Re-meandering would increase habitat diversity, reduce water depths and allow wet meadows to develop on adjacent floodplain. Organic farmer owning one reach is interested in the prospect. It is feasible and costs would be realistic.

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
In all mitigation cases
Macrophytes – (Impact High)
Fish – limited hydraulic habitat (Impact High)
Benthic invertebrates – (Impact High)
Algae – slow flowing (?)

Channelisation - *Rural*

CHANNELISATION - *URBAN*

ID 4736 Polmaise Burn (Site from which photographs taken – LAT 56 01 008 LONG 003 43 123

MORPHOLOGICAL DESCRIPTION
A straight channel with wood piling banks (3 metres width). Runs through a housing estate bordered by a corridor of trees and grassy banks. Low gradient, rectangular channel and silty bed. No habitat diversity.

DRIVING FORCE/ACTIVITY
Channel straightening/urban development

PRESSURE
River straightening

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – too deep and turbid (Impact High)
Fish – limited hydraulic habitat (Impact High)
Benthic invertebrates – (Impact High)
Algae – slow flowing (?)

The reach should fail on Hydromorphological quality

RESPONSE/POSSIBLE MITIGATION TECHNIQUES
Re-meandering (one side) – feasible
Re-meandering (either side) – possibly feasible
Re-design straight channel to sinuous multi-channel river – feasible and desirable
Restore channel – possibly feasible and desirable
Reconnection of cut-off meanders – no evidence of old meanders
Aquatic ledges – possible
Current deflectors – possible
No other measures appropriate

APPROPRIATE MITIGATION AND RESTORATION
Re-meandering would increase habitat diversity and quality. It is feasible although the room available is limited due to development either side of the river corridor. Aquatic ledges may aid macrophyte growth and deflectors would instill a number fow flow types Planting of the corridor would be advantageous. Costs would be realistic.

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
Remeandering
Macrophytes – (Impact High)
Fish – (Impact Medium)
Benthic invertebrates – (Impact High)
Algae – (Impact Zero)
Aquatic ledges
Macrophytes – (Impact High)
Fish – (Impact Low)
Benthic invertebrates – (Impact Low)
Algae – (Impact Low)
Current deflectors
Macrophytes – (Impact Low)
Fish – (Impact Low)

Benthic invertebrates – (Impact Low)
Algae – (Impact Zero)

Channelisation - *Urban*

ID 4503 Burn of Sorrow (Site from which photographs taken – LAT 56 09 850 LONG 003 40 281

MORPHOLOGICAL DESCRIPTION
A straight channel of approximately 5 metres width with stone banks Bordered by roads on either side. Steep gradient, rectangular channel and coarse gravel bed. Upstream the river flows through an impressive gorge and is high energy. A flood in the late 19th century ravaged the town with a.number of houses washed away and deaths; the name says it all. Hence the channelised reach.

DRIVING FORCE/ACTIVITY
Channel straightening/urban development

PRESSURE
River straightening

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – Few would be present in natural channel
Benthic invertebrates – (Impact Medium)
Fish (Impact Medium)
Algae – slow flowing (?)

The reach should fail on Hydromorphological quality alone but biological impact limited

RESPONSE/POSSIBLE MITIGATION TECHNIQUES
Re-meandering (one side) – not feasible
Re-meandering (either side) – not feasible
Re-design straight channel to sinuous multi-channel river – not feasible
Restore channel – not feasible
Reconnection of cut-off meanders – not feasible
Current deflectors – would not significantly alter hydraulic habitat diversity due to rough and steep nature of the bed
No other techniques appropriate

APPROPRIATE MITIGATION AND RESTORATION
None really feasible and advantageous given the setting.

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
No techniques thought appropriate

Channelisation - *Urban*

INTENSIVE USE - *RURAL*

ID 4722 Drunkie Burn (Site from which photographs taken – LAT 56 01 008 LONG 00 03 43 123

MORPHOLOGICAL DESCRIPTION
A natural coarse gravel bed river of 10 metres width with relatively high gradient and well developed pools and riffles. The river corridor at the sites inspected was deciduous woodland although the catchment is under commercial forest. Some removal of conifers has occurred. The site is known to be highly acidified. If there are reaches where the proximity of the conifers is causing light limitation removal would be preferable.

PRESSURE
Agriculture

DRIVING FORCE
Intensive land use

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – (Impact Low)
Fish – limited spawning habitats (Impact Low)
Benthic invertebrates – (Impact Low)
Algae – slow flowing (?)

The reaches inspected should not fail on Hydromorphological quality

RESPONSE/POSSIBLE MITIGATION TECHNIQUES
APPROPRIATE MITIGATION AND RESTORATION
Introduce buffer zones (technique 101). Conifer removal is required. Costs would be realistic.
Increased light penetration, organic input may increase macrophyte and invertebrate abundance and diversity
No other techniques appropriate

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
Macrophytes – (Impact Low in reaches observed)
Fish – (Impact Low in reaches observed)
Benthic invertebrates – (Impact Low in reaches observed)
Algae – Impact Low

Intensive Use - *Rural*

WEIRS

ID 6832 Allan Water (Site from which photographs taken – LAT 56 09 080 LONG 00 03 53 1943

MORPHOLOGICAL DESCRIPTION AND STATE
A natural coarse gravel bed river of 20 metres width with relatively high gradient and well developed pools and riffles. Low weir to divert water to lade for now disused mill. Weir a barrier to salmonid migration except at high flows.

DRIVING FORCE/ACTIVITY
Physical presence of weir (past activity; formerly to divert water down lade to mill)

PRESSURE
Continuity

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – (Impact Zero)
Fish – limits upstream migration (Impact Medium)
Benthic invertebrates – (Impact Low)
Algae – slow flowing (?)

The reaches inspected should not perhaps fail on Hydromorphological quality even though there is disruption to continuity

RESPONSE/POSSIBLE MITIGATION TECHNIQUES

(Physical presence of dam)
Potential measures
Filtration to remove particulate organic matter in reservoir: Not necessary as water behind weir still maintains a gravel bed
Introduce fish pass: Baffled pass would aid upstream migration
Flushing of sediment: Not necessary as limited affect as the weir has limited affect on sediment transport
The following techniques were considered not to be appropriate for a weir of this scale: Controlled release of sediment; Riparian habitat restoration; Fish restocking; Capture/release fish as required; (Re)planting of native macrophyte species; Removal of weirs; Locate impoundment off-line; Canoe passage; Provide lock; Reduce angle of lake sides; Plant marginal species.

Pool and traverse fish pass – not necessary given low impact
Notch cut in weir -feasible

APPROPRIATE MITIGATION AND RESTORATION
Notch cut in weir. Costs would be realistic.

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
Macrophytes – (Impact Zero)
Fish – Improve upstream migration success rates (Impact Medium)
Benthic invertebrates – (Impact Zero)
Algae – Impact Zero

Weirs

BANK REINFORCEMENT

ID 6832 Allan Water (Site from which photographs taken – LAT 56 11 253 LONG 00 03 57 922

MORPHOLOGICAL DESCRIPTION AND STATE
A natural coarse gravel bed river of 20 metres width with a moderate gradient and well developed pools and riffles. Walled channel supporting walkway

DRIVING FORCE/ACTIVITY
Urban development

PRESSURE
Bank reinforcement

ECOLOGICAL IMPACT OF ORIGINAL MODIFICATIONS
Macrophytes – (Impact Low)
Fish – (Impact Low)
Benthic invertebrates – (Impact Low)
Algae – (Impact zero)

The reaches inspected should not perhaps fail on Hydromorphological quality even though there is bank reinforcement

RESPONSE/POSSIBLE MITIGATION TECHNIQUES
Aquatic ledges

APPROPRIATE MITIGATION AND RESTORATION
Aquatic ledges. Costs would be realistic.
Improve river margin substrate for macrophyte/riparian tree development

ECOLOGICAL IMPACT OF SELECTED MITIGATION TECHNIQUES
Macrophytes – (Impact Medium)
Fish – (Impact Low)
Benthic invertebrates – (Impact Zero)
Algae – Impact Zero

Bank Reinforcement

GENERAL OBSERVATIONS

- The tables and approaches designed do provide a useful framework for considering at-a-site river restoration options and desirability. However assessment of feasibility and ecological impact requires expert opinion and may not be able to be undertaken by SEPA environmental protection officers but only those with ecological/geomorphological training. The list of mitigation methods is exhaustive but at some sites hydromorphological improvement may not be possible.

- The pressures as identified by SEPA are generally accurate.

- In the case of intensive land use and commercial afforestation I was informed that affected reaches were determined using OS map data. My field observations suggest that this is unreliable since even where rivers and stream are depicted as flowing through a forested catchment there can be an unaffected river corridor. Aerial photography is really required to assess the proximity of a land use to the river banks and show evidence, for example of canopy closure over the river. Linked to this, as I understand it, SEPA give the OS grid reference of the mid point of affected reaches as defined on SEPA,s digital river network and thus the geo-referencing of the pressure is not accurate. This is significant in the that the length of reaches shown on the SEPA tables is the length of the pre-defined reaches and not the reach impacted by a particular pressure (eg 23.771 km of Duchray Water is not impacted nor is 6.203 km downstream of Dunblane on the Allan Water). In other word the reach length values can not really be used for defining costs.

- The mitigation techniques table is a useful and comprehensive information sheet on which to assess mitigation option for the pressure at a particular site.

- There are sites listed such as embanking on the Tweed where there is no ecological impact on the instream system but they do affect riparian and floodplain habitat. It's all about reference condition I suppose.

- The ecological impact could be scored as 0-3 (zero to high) for each of the four ecological categories (macrophytes –algae) and then totalled. This divided by cost could be a good rudimentary cost benefit analysis.

Appendix II Sample costs from past schemes

Specific pressures	Potential Measures	Costing Information					Comments
		Rural	Urban	Technique	Estimated Cost (£) 2004	River Length restored	
River substrate manipulation	Removal of artificial bed material (concrete – gabion)		*	Remove river from concrete channel	1144000	300m	*Costs include entire project not just removal of artificial bed material
	Removal of artificial bed material (concrete – gabion)		*	Remove river from concrete channel	1226400	500m	*Costs include entire project not just removal of artificial bed material
	In channel habitat improvements (e.g. return natural substrate to channel)		*	Replace concrete drain with natural channel	6600	1000m	
Bed and bank reinforcement	Replacement with more natural solutions (soft engineering structures)		*	Willow spilling	138/m	75m	
			*	Log and toe geotextile revetment with willow slips	178/m	91m	
			*	Willow Mattress revetment	200/m	59m	
			*	Plant roll revetment	158/m	119m	
		*		Hurdle and coir matting revetments	49/m	15m (hurdles) / 20m (x3) (matting)	
		*		Bank revetment (steel piling and coir rolls)	54000	140m	
River resectioning	Cessation of maintenance, allow banks and riparian zone restore natural profile/structure	*		Reduction in maintenance costs (due to increase sinuosity and narrowing)	3500 saving	500m	
	In-stream habitat enhancement measures		*	Stone riffles*	2400	60m	
			*	Low cost groynes	2340	125m	
			*	Current Deflectors	1220 each	N/A	
	Seeding/Planting in riparian zone to create natural bank features/structure	*	*	N/A	5/m2	N/A	*Quote provided by British Flora
River straightening	Restore straightened sections	*		Re-meandering (one-side)	10980	500m	
		*		Re-meandering (either side)	30500	700m	
				Re-meandering (one-side)	46800	500m	
			*	Re-design straight channel to sinuous multi-channel river	46800	140m	
			*	Restore channel	36000		
			*	Reconnection of cut-off meanders	18360		
	make the channel narrower		*	Current Deflectors	1220each		
			*	Aquatic ledges	50/m		
			*	Low cost groynes	2200	125m	
		*		Aquatic ledges	62/m		
	Leave river to reform pools and riffles	NO COST	NO COST				
	Re-connecting existing meanders to main channel	*		Reconnecting remnant meanders	18750	900m	
	Introduction of in channel structures to increase flow diversity	*		Stone riffles*	2440	60m	
		*		Low cost groynes	2350	125m	
		*		Current Deflectors	1250each		
River realignment	Re-connecting existing meanders to main channel	*		Reconnecting remnant meanders	19000	900m	
			*	Reconnection of cut-off meanders	22500		
	Initiate natural planform/meanders	NO COST	NO COST				
	Introduction of in channel structures to increase flow diversity	*		Stone riffles*	2450	60m	
		*		Low cost groynes	2400	125m	
		*		Current Deflectors	1280each		
River channelisation	Re-connecting existing meanders to main channel	*		Reconnecting remnant meanders	19200	900m	
			*	Reconnection of cut-off meanders	20000		
	Initiate natural planform/meanders	NO COST	NO COST				
	Introduction of in channel structures to increase flow diversity	*		Stone riffles*	2440	60m	
		*		Low cost groynes	2350	125m	
		*		Current Deflectors	1250each		
Culverting	Opening-Removal of culverts (link to flood reduction measures)	*	N/A		132000	300m	
			*	Deculverting	312500		
	Introduce minimum flows	?	?				
Impounding	Build in fish passages	*	N/A	Pool and traverse fish pass	59000		
	Improve existing fish passages	*		Weir bypass via ditch	35000		
			*	Notch cut in weir	3125		
	Removal of weirs	*		Removal of low weir/modification work	6400		
Constriction	Removal of weirs	*		Removal of low weir/modification work	6400		
	Replace current road bridges with single span bridges,						
			*	1	120000		
				2	270000		
			*	3	420000		
Intensive use	Introduce buffer zones adjacent to river			4	40000		
	Reduce grass cutting and other vegetation management	SAVING	SAVING				
	Removal of embankments	*		Removing and setting back floodbanks	75000	900m	
	Re-connection with floodplain Allow natural flood storage on floodplain	*		Floodplain wetland mosaic	200000	1.5ha (area)	
	Promote establishment of natural floodplains (links to recreation opportunities)		*	Flooplain scrapes	1250 each		
	(LINK)		*	Lake flood storage basin	38000		
		*		Floodplain pond	31250		

Bridge No	Existing	Clear Span	C'way	Public Use?	Traffic M'ment?	Over River?	Cost
1	No	10m	Single	No	No	No	£120k
2	No	10m	Single	No	No	Yes	£275k
3	No	10m	Two	Yes	Yes	No	£420k
4	No	3m	Single	No	No	Yes	c£40k

1. Costs for bridges 1, 2 and 3 do NOT include normal contract overheads, i.e. staff supervision, mobilisation, insurances, profit, etc. These are priced estimates for an Environment Agency scheme using Framework Contractors.
2. Bridge 4 was carried out on a private estate by a local contractor.
3. Bridges 1, 2 and 4 are farm accesses – 4m width, Bridge 3 is a B Road (i.e. one lane in each direction)
4. Bridge 3 had to be constructed in two parts, with traffic management during construction
5. Bridge 2 had to be constructed over an existing river, with no alternative access to the far side. Bridge 4 had a ford for access. The others were to be constructed prior to a diversion channel being diverted under them

Appendix III Establishing the mitigation costs to bring the quality of rivers and lochs up to standard

Establishing the mitigation costs to bring the quality of rivers and lochs up to standard

The mitigation costs for each section for river and loch are calculated individually in the spreadsheet called Summary of Costs, these cost are also summarised, for each mitigation activity, within this spreadsheet. All the relevant information is contained within this sheet. If any of the variables that affect the cost, or the validity of the cost, change then this must be updated within this sheet.

Description of Worksheets within the Spreadsheet
There are two types of worksheet within this spreadsheet. There are reference sheets and calculation sheets.

The reference sheets are:

- **Unit_Cost_River:** Unit cost to mitigate pressure for a river
- **Unit_Cost_Loch:** Unit cost to mitigate pressure for a loch (this is identical to Unit_Cost_River at present, but has been included as a separate reference sheet to allow for flexibility in the future)
- **HMWB_ABW:** Defines whether the waterway is either a pHMWB or an AWB
- **Quality_and_Standards:** Details if the work required has already been budgeted for
- **IS_River:** Details the industrial sector which the river section can be described as, this sheet is not used in evaluating the costs or summarising them
- **IS_Loch:** Details the industrial sector which the loch section can be described as, this sheet is not used in evaluating the costs or summarising them

The calculation sheets are:

- **Mitigation_Costs_Rivers:** Calculates the cost to mitigate each pressure for each river section and establishes if the work is necessary (e.g. is it either a pHMWB or an AWB) and whether the work has not been budgeted for yet.
- **Mitigation-Costs_Lochs:** Same as Mitigation_Costs_Rivers but for Lochs
- **Summary:** Summarises the total cost of work required for each pressure for both Rivers and Lochs

Variables considered in calculating the costs
In the reference sheets there are a number of variables that are used to calculate the mitigation cost, these are:

1) Mitigation Costs per Activity (Cost in £)
2) Percentage of waterbody affected by pressure (%)
3) Is mitigation cost an individual cost or is it dependent on the length of (Yes/No)
4) Length of waterbody segment (m)
5) Pressure (Pressure #)
6) Category of waterbody (Is pHMWB/AWB)
7) Total number of waterbody pressures [number of rows detailing individual costs]

A number of these variables are not expected to change. But details of how to change them are included for reference on how they effect the calculation of the actual costs.

Variables 1, 2 and 3 can all be changed in the Unit_Cost_River and Unit_Cost_Loch sheets. To change the unit cost over-write the value in the “Cost per metre” column. If the pressure represents a one off cost, ensure the “Is single cost” column is Yes, otherwise leave this column as No.

If a pressure is a unit cost then the “Minimum %” and “Assumed %” should both be set to 0%. The percentage of waterbody affected can be changed in the “Assumed %” column, the value entered here must be greater than or equal to the “Minimum %”.

It is not expected that new pressures will need to be added, however if new pressures are added then the automatic lookup functions in the calculation sheets will need to be updated.

The length of waterbody (variable 4) is not expected to change, this can be found in both the Mitigation_Costs_Rivers and Mitigation_Costs_Lochs sheets. To change this, simply over-write the existing value.

The pressure number (variable 5) can also be found in both the Mitigation_Costs_Rivers and Mitigation_Costs_Lochs sheets. If the pressure that a waterbody is affected by changes, change the “Activity Abbreviation Code” in these sheets, the consequences of this should be automatic. If a waterbody is subject to a new pressure, a new row will have to be inserted (with a unique pressure ID (Press ID), and the new pressure written in there). The simplest way to do this is to copy the existing row for that waterbody and then insert a duplicate below it, then change the Activity Abbreviation Code and the Pressure ID. This will increase the total number of individual costs (variable 7) and this will require the “Summary” sheet to be updates so that it can establish the cost per mitigation activity from all of the individual pressures.

Variable 6 can be updated in the HMWB_ABW worksheet. If the designation of a waterbody changes, column L should be updated in this sheet. If a waterbody that hasn’t previously been designate needs to be added, this should be added at the bottom of the table and column D calculation sheets Mitigation_Costs_Rivers and Mitigation_Costs_Lochs so that the additional rows in the HMWB_ABW worksheet are searched.