Final Report **Project WFD29**

Management Strategies and Mitigation Measures Required to Deliver the Water Framework Directive for Impoundments

Volume 1 – Preliminary Guidance Document

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EXECUTIVE SUMMARY

WFD29: Management Strategies and Mitigation Measures required to deliver the Water Framework Directive for Impoundments

Project funders/partners:
SNIFFER;
Scottish Environment Protection Agency (SEPA); and
Environment Agency (EA).

Background to research

The implementation of the EC Water Framework Directive (WFD) requires the development of new approaches and methodologies by the competent authorities in the United Kingdom. One of these requirements involves developing procedures to ensure the adequate mitigation of the negative impacts created by the construction and operation of impoundments. Any activity to mitigate the environmental impact of an impoundment must reconcile the protection of the local aquatic ecology with the socio-economic benefits of impoundments and must fit within the overall river basin management planning process.

Objectives of research

The Objective of the project is to provide a Guidance Document which presents a user friendly guide for identifying best practice and cost-effective management strategies and mitigation measures for potential application to impoundments for hydro-power, flow regulation and water supply in order to meet the requirements of the Water Framework Directive in the UK.

Key findings and recommendations

The initial international review of impoundment management practices provided a legislative, planning, management and regulatory context for impoundments across five countries (Norway, France, Germany, Australia and USA) and identified typical and good practice mitigation measures. The review found that the licensing procedures in all countries were broadly similar. A two tiered approach to licensing, Environmental Impact Assessments for large impoundments and consultation with statutory and non-statutory bodies were evident in all countries and the majority of the countries applied the concept of time-limited licensing and the incorporation of conditions in the license to mitigate impacts on the surrounding environment.

A preliminary analysis of the mitigation techniques tried and tested by the five different countries showed that a substantial number are commonly used by all (e.g. compensation flows, fish passes, fish screens and measures to improve dissolved oxygen levels and maintain natural temperatures). Novel approaches were also identified (e.g. salt interception systems close to the coast in Australia, fish friendly turbines to prevent fish damage in USA, fish passes specifically for eels and a retaining weir dam to maintain water levels in an isolated area of the impounded water (Norway)).

The key elements of the Guidance Document are:

- a step-by-step approach – from defining the drivers and pressures on a system to identifying a potential solution or combination of cost-effective solutions;
- a set of ten Guidance Sheets, which cover the main environmental / management issues facing impoundment management (including topics such as hydro-peaking flows, fish migration etc.), cross-referenced to the mitigation measures database and the conceptual models;
- a spreadsheet of more than 100 practical mitigation measures and management strategies that could be considered;
- a spreadsheet of the potential indicative cost of those measures and strategies (where known);
- consideration of the broader environmental and technical issues associated with the implementation of the mitigation measures and management strategies (e.g. flood management, social, recreational and navigation implications etc.);
- conceptual models of impoundments for hydropower, flow regulation and water supply in the UK; and
- a comprehensive reference list for further information on individual techniques and strategies.

Additional discussion is also provided on:

- the construction and decommissioning of impoundments;
- the impacts of impoundments on sustainable flood management practices; and
- considerations for impoundments associated with coastal and transitional waters.

The Guidance Document has been prepared in the light of:

- an international review of best practice mitigation measures and management strategies;
- a Steering Group of experts within the Scottish Environment Protection Agency (SEPA) and the environment Agency (EA);
- technical experts on the project team from a wide range of disciplines;
- a workshop with key stakeholders (including impoundment managers, environmental consultees, British Dam Society and SEPA / EA licensing officers).

The Guidance Document has been amended in light of recommendations made following trials by SEPA / EA licensing officers and private sector impoundment managers on the River Dee (Wales) and the Glendevon (Scotland).

The principal users of this guidance are envisaged to be the regulatory authorities (particularly SEPA and EA water resources licensing officers) and impoundment managers (private and public sector). The preliminary and final document can be used when:

- considering what conditions to include when licensing impoundment structures under the new licensing regime (in Scotland this is anticipated at the end of 2005);
- undertaking reviews of existing impoundment licences under the requirements of the WFD.

It is intended that the methodology suggested in this preliminary guidance document will enrich the discussion of alternatives in public decision-making. It is important to note that the document contains the best recommendations of the consultants and does not necessarily represent the official views of SEPA and the EA.

Key Words
Water Framework Directive; impoundments; mitigation measures; cost effectiveness.

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1 INTRODUCTION

1.1 Background

This document was commissioned by SEPA and the EA (SNIFFER Project WFD29) to support the implementation of the Water Framework Directive (WFD) regarding the necessary measures to mitigate the negative impacts of impoundments. The Water Framework Directive came into force in December, 2000. The key objective of the WFD is achieving *good ecological status* (natural waterbodies) or *good ecological potential* (heavily modified or artificial waterbodies) for all European waterbodies by 2015.

The implementation of the EC Water Framework Directive (WFD) requires the development of new approaches and methodologies by the competent authorities in the United Kingdom. One of these requirements involves developing procedures to ensure the adequate mitigation of the negative impacts created by the construction and operation of impoundments. Any activity to mitigate the environmental impact of an impoundment must reconcile the protection of the local aquatic ecology with the socio economic benefits of impoundments and must fit within the overall river basin management planning process.

1.2 Objective

This report is a preliminary guidance document, intended to assist both agency staff and impoundment managers in identifying the most appropriate set of mitigation measures that will be required to achieve the WFD objective for impoundment projects in the United Kingdom. The methodology provided in this document considers socio-economic issues, technological alternatives and capital investment constraints alongside the environmental and ecological issues.

The SNIFFER Project WFD29 was divided into three phases: Phase 1 - International Review of Impoundment Management Strategies; Phase 2: preparation of a Guidance Document of Management Strategies and Mitigation Measures for Impoundments; and Phase 3: Trials of the Guidance Document. Due to the vast quantity of information and the technical nature of the outcomes, this report was been divided into two Volumes (technical guidance and appendices) as described in Section 2 below.

This preliminary guidance document was developed in accordance with the project brief published by SNIFFER, with the proposal presented by Posford Haskoning and the Centre of Ecology and Hydrology (CEH) in 2003, and with direction from the Client Steering group and the internal project team steering group including international specialists (see contact VOLUME 2, Appendix 13). The document will be used by SEPA to prepare an official Guidance Document.

The preliminary and final document can be used when:

– considering what conditions to include when licensing impoundment structures under the new licensing regime (in Scotland this is anticipated at the end of 2005);
– undertaking reviews of existing impoundment licences under the requirements of the WFD.

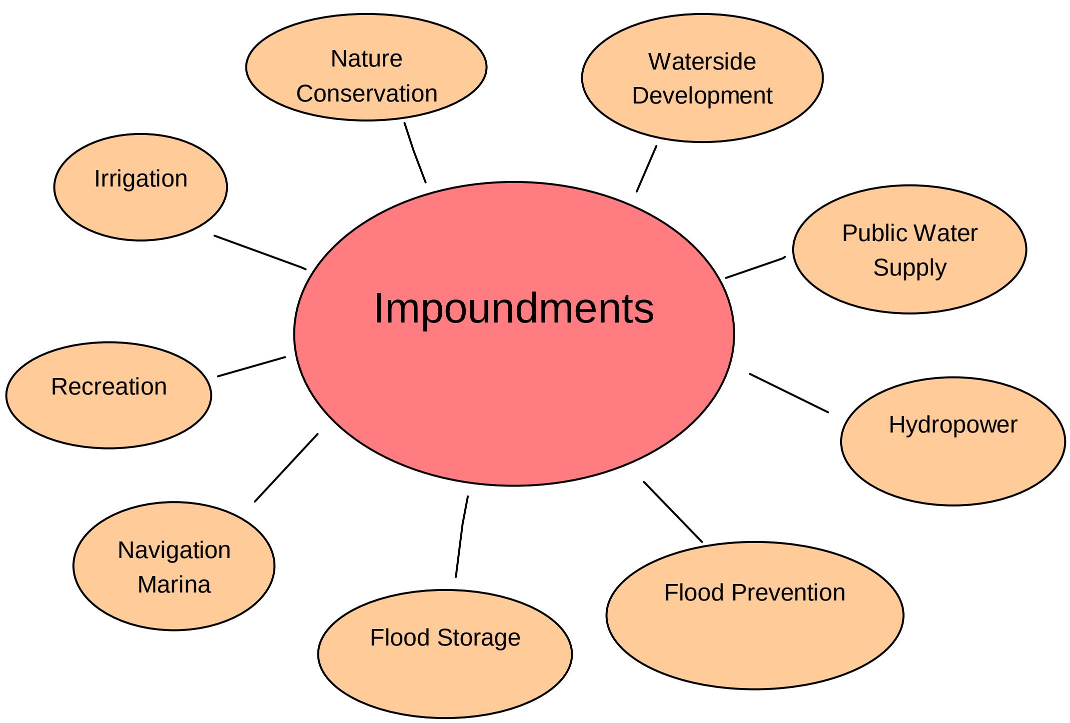
It is intended that the methodology suggested in this preliminary guidance document will enrich the discussion of alternatives in public decision-making. It is important to note that the document contains the best recommendations of the consultants and does not necessarily represent the official views of SEPA and the EA.

1.3 Scope

The Water Framework Directive (WFD) covers all water bodies (freshwater, groundwater, transitional water and coastal water) and that a wide variety of impoundment types could be considered (Figure 1.1).

The term 'impoundment' includes a range of structures, particularly dams and weirs, that are built to store water, control water levels, or divert water flows in order to satisfy many different social and economic purposes. Depending on the location, scale and the operational practice of each scheme, they can create distinct and potentially very significant environmental impacts. The most common impacts are due to changes in the hydrological flow regime and to natural geomorphological processes within a catchment. These can alter the VOLUME, velocity and depth of flows, the passage of biota and sediment transport. They may also cause a degradation of riparian areas and alter the interaction between an affected river and its natural floodplain.

Figure 1.1 Variety of Impoundment Types



However, this project was focussed on management and mitigation strategies for freshwater hydropower impoundments and dams for water supply and flow regulation. Nevertheless, the proposed methodology and the majority of the mitigation techniques identified and provided in this report are expected to be relevant for other impoundment types as well.

1.4 Legislative context

The purpose of the Water Framework Directive (WFD) is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwaters which:

A. prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on aquatic ecosystems;
B. promotes sustainable water use based on a long term protection of available water resources;
C. aims at enhanced protection and improvement of the aquatic environment, *inter alia*, through specific measures for the progressive reduction of …..priority substances………..;
D. ensures the progressive reduction of pollution of groundwater…………;
E. contributes to mitigating the effects of floods and droughts.

(Reference: Article 1 WFD 2000/60/EC)

The environmental objectives of the WFD for surface waters are:

A. that member states shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water;
B. member states shall protect, enhance and restore all bodies of surface water with the aim of achieving good ecological status (GES) and good surface water chemical status by 2015;
C. Member states shall protect and enhance all artificial and heavily modified bodies of water with the aim of achieving good ecological potential (GEP) and good surface water chemical status by 2015.

(Reference: Article 4 WFD 2000/60/EC)

Good ecological potential and good ecological status are measured in terms of the following biological elements:

- Phytoplankton;
- Macrophytes and phytobenthos;
- Benthic invertebrates;
- Fish fauna.

In case of natural waters, the composition and abundance of these biological quality elements are required to be close to 'undisturbed conditions' for a water body to be defined as being at GES. GEP is defined as the situation in which the biological, hydromorphological and physico-chemical quality elements deviate slightly from the maximum ecological potential (MEP) that is achievable for the water body.

Under the provisions of the WFD, water bodies require a good hydro-morphological status and a good physico-chemical status in order to support the biological elements that ensure GES/GEP is achieved. It is therefore assumed in this study that these are preconditions for GES/GEP and hence need to be considered when identifying potential problems and solutions required.

1.5 International review

VOLUME 2, Appendix 1presents the findings of the international review of impoundment management practices, which provides a legislative, planning, management and regulatory context for impoundments across five countries (Norway, France, Germany, Australia and USA) and identifies typical and good practice mitigation measures. The review considered impoundments for hydropower, water supply and flow regulation.

A two-tiered approach to licensing appears to be a common theme throughout the five countries and a Environmental Impact Assessment is used by all five for large impoundments. Consultation with statutory and non-statutory bodies was evident in all the countries reviewed, both for the licensing and re-licensing of dams. The multiple stages for consultation and the extent to which the public is involved are considered to be a valuable element of the (re)licensing procedures in Norway, the USA and France.

The majority of the countries evaluated apply the concept of time-limited licensing and the incorporation of conditions in the license to mitigate impacts on the surrounding environment. These concepts are deemed as effective regulatory techniques, worthy of consideration in the UK.

A preliminary analysis of the mitigation techniques tried and tested by the five different countries showed that a substantial number are commonly used by all (e.g. compensation flows, fish passes, fish screens and measures to improve dissolved oxygen levels and maintain natural temperatures). Novel approaches were also identified (e.g. salt interception systems close to the coast in Australia, fish friendly turbines to prevent fish damage in USA, fish passes specifically for eels and a retaining weir dam to maintain water levels in an isolated area of the impounded water (Norway)).

Decommissioning of at least three large dams was identified in France in recent years, whilst the USA was clearly actively decommissioning large dams. Decommissioning is not currently a major issue in Norway and Australia

2 USE AND STRUCTURE OF THIS PRELIMINARY GUIDANCE DOCUMENT

The approach suggested in this preliminary guidance document focuses primarily on the identification of mitigation measures for **existing** impoundment structures. Moreover, the step by step process detailed in section 3 can be adapted for proposed impoundment structures.

Compliance with the requirements of this report does not mean that a licence for the impoundment structure will automatically be granted by the agency and impoundment managers should also be aware that the granting of an impoundment license does not mean that a proposed impoundment can be constructed, unless planning permission from the local council has been obtained.

This document forms VOLUME 1 of a two-VOLUME report and consists of a number of tools which can be used as follows:

- a ***practical step by step approach*** (section 3) to selecting the most appropriate (combination of) measures to meet the 2015 WFD objectives for all impoundment types which takes into consideration ecological, socio-economic and financial issues and constraints. To be applied properly, it must be read in conjunction with the other sections of the document and the technical appendices;
- ***detailed guidance sheets*** (section 4) covering the main environmental and management issues for impoundments. These sheets can be used for background information, and illustrate the approach to selecting the most suited (combination of) mitigation measures;
- ***additional considerations*** for the design, construction and decommissioning stages (section 5) ;
- a comprehensive ***reference list*** (section 6) is provided for further information on mitigation measures and management strategies.
- a ***mitigation measures and management strategies spreadsheet*** (Tables Section and accompanying CD Rom) which outlines more than 100 potential measures identified to date that could be used to protect, enhance and restore impoundment water bodies and their associated rivers, to achieve good water status and good ecological potential;
- a ***costings spreadsheet*** (Tables Section and accompanying CD Rom) with relevant financial information which can be used in the process for selecting the most cost-effective measures and combinations of measures;

In addition to the information contained in Volume 1, Volume 2 containes a serie of which of technical appendices have been prepared which provide additional, essential information which will assist in the selection of the most appropriate and cost effective measures. There are 13 technical appendices and these are detailed in Table 2.1 overleaf.

Table 2.1: Contents of Technical Appendices (Volume 2)

Appendix 1	International review of impoundment management practices
Appendix 2	Guidance on setting ecological targets
Appendix 3	The effects of impacts and mitigation measures – an ecological View
Appendix 4	Driving forces, pressures and resultant impacts
Appendix 5	Best practice mitigation measures for specific impoundment pressures
Appendix 6	Conceptual models
Appendix 7	Cost effective analysis
Appendix 8	Blank tables and forms
Appendix 9	SNIFFER WFD29 Workshop information
Appendix 10	Example of the assessment process
Appendix 11	References for technical appendices
Appendix 12	Trials of draft guidance
Appendix 13	Contacts

All the information in both Volumes is important to assist in the determination of the appropriate mitigation measures required for each impoundment. Consequently, it is advised that users first familiarise themselves with the step by step approach outlined in section 3 and the guidance sheets in section 4. The users will then be able to apply the step by step approach, utilising the information in the other sections and VOLUME as necessary. To further assist in the process, a flow chart showing the process and the relevant documentation and other sources of information which should be consulted at each stage in the process is shown in Figure 3.1.

3 PRACTICAL APPROACH FOR SELECTING MOST APPROPRIATE MITIGATION MEASURES

3.1 Introduction

The following approach is designed to select the most appropriate (combination of) measures for mitigating the environmental impact of an impoundment required to meet the target WFD environmental status (GES or GEP).

When selecting (a combination of) measures, it is important that the environmental objectives are realised and, at the same time, that financial costs and negative social/economic effects are as low as possible. In a cost-effectiveness analysis, the socio-economic and financial costs are compared to the expected benefit for the WFD biological elements (fish, invertebrates, macrophytes, phytobenthos and phytoplankton).

The WFD therefore requires that the cost-effectiveness of potential mitigation measures is assessed, to ensure that the costs (financial and socio-economic) of implementing the requirements of the Directive are not excessive in comparison to the primary benefits accrued by impoundment construction, management and decommissioning. Further socio-economic analyses can be required to determine if the costs are disproportionate and this may trigger an application for derogation (the methodology to determine disproportionate costs and derogation is beyond the scope of this project).

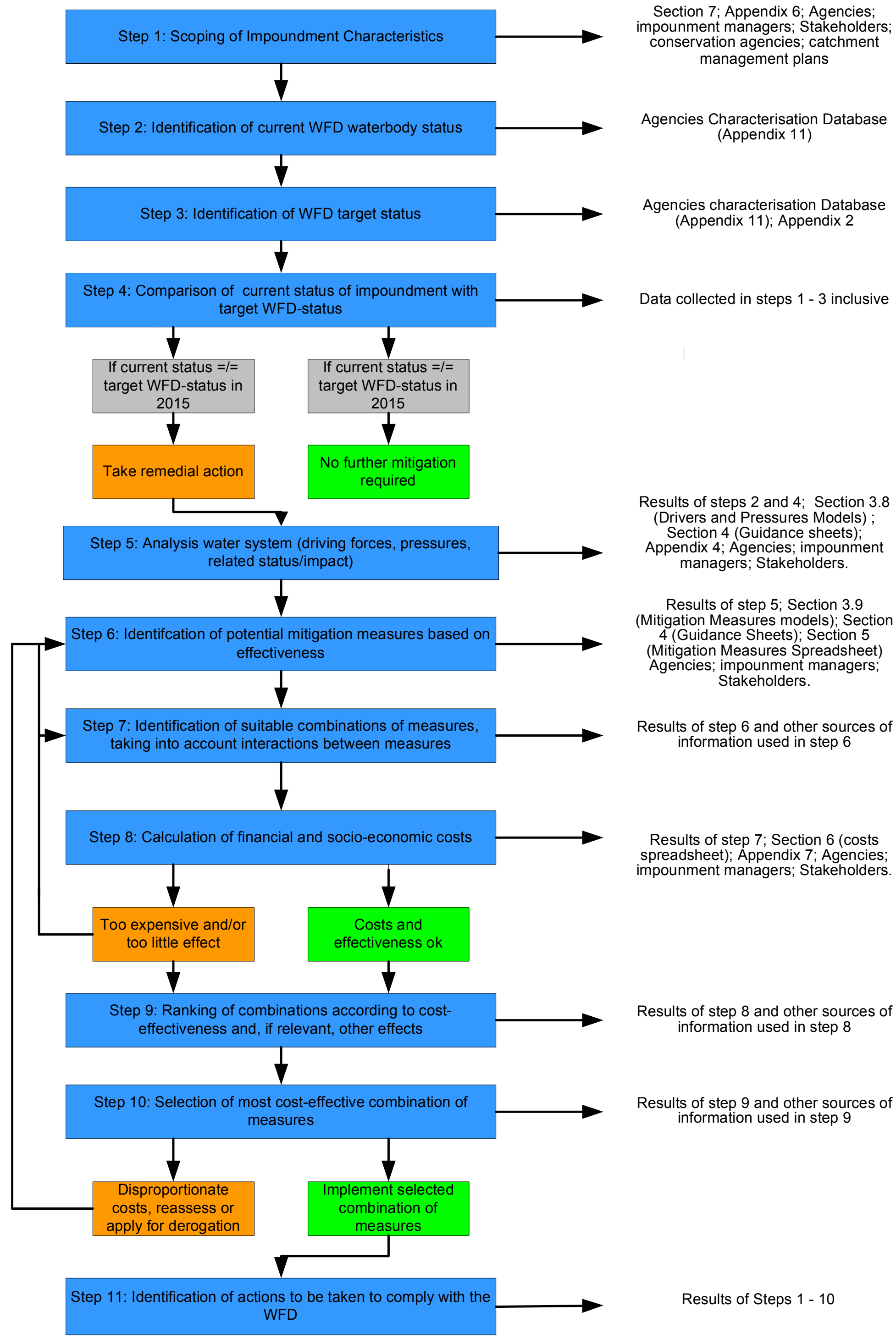
The selection of the most suited combination of measures is a complex process. This guidance aims to break it down into eleven key steps which provide a logical, clearly understandable and transparent procedure. Following this procedure will ensure that the final selection of measures is based on the specific characteristics of, and problems identified in the water system being considered.

3.2 Eleven steps in selecting most appropriate combination of measures

The eleven steps of the selection process are presented in the flow chart in Figure 3.1. A case study illustrating how the process works in practice is shown in VOLUME 2, Appendix 10.

Each step is discussed in sections 3.4 to 3.14 below. In order to keep this section as brief as possible, references to additional supporting information elsewhere in the Volumes 1 and 2 are given where appropriate. As mentioned in section 2, it is important that the users take the time to familiarise themselves with the complete contents of this guidance, as this will ensure that the users are fully aware of the background to the process and understand the implications of assumptions and decisions made. It is also vital to ensure that local knowledge and experience of the impoundment managers and other users is sought out and taken into account.

Figure 3.1: Eleven steps for selection of appropriate measures



3.3 Audit trail for the process

It is essential to provide an audit trail for the cost-effectiveness analysis. This should systematically record the information collated and decisions and assumptions made. This is particularly important because information is likely to be assembled from diverse sources, and may be of varying quality. Furthermore, there will often be a need for expert judgement, and the grounds for decisions need to be stated so that they are clear when assessments are revisited.

A series of blank tables have been included in this section and summarised for easy replication in, Appendix 8, VOLUME 2. These should be completed as the analysis progresses. For cascade systems with multiple impoundments, additional columns should be added as necessary or an individual table completed for each impoundment. Examples of completed tables can be found in VOLUME 2, Appendix 10, which details a case study to demonstrate how the preliminary guidance could be used in practice.

3.4 STEP 1: Scoping of impoundment characteristics

The objective of this step is to collate general information on the characteristics of the impoundment(s) which will be used in following steps of the process. The information will be used to identify pressures (step 5) and potential mitigation techniques (step 6), as well as other issues which need to be considered, such as socio-economic costs and existing habitats and protected areas (SSSI's etc). The characteristics which should be considered are listed in tables 3.1a and 3.1.b. Other aspects which are not included in the table but are considered relevant to the ecological status and potential and the potential for mitigation at a particular location can be added as necessary. Where the system consists of a number of linked impoundments (a cascade system), each impoundment should be considered individually before the system is considered as a whole.

In addition, a map of the system will be a useful tool in completing this step. As indicated in the flowchart in figure 3.1, consultation with the environmental agencies, impoundment managers and other stakeholders is highly recommended to ensure that this step incorporates all relevant environmental, technical and socio-economic issues.

This step can be carried out simultaneously with steps 2 – 4, but must be completed before starting with step 5.

Table 3.1a: Summary of information relating to catchment

Reservoir	Reservoir 1	Reservoir 2
Catchment area		
Surface area of reservoir		
Total capacity/VOLUME		
Maximal Depth		
Maximal draw down depth*		
Compensation flow		
Dam height		
Dam length		
Dam type		
Dam purpose		

** report in metres above bed of reservoir i.e. maximal depth of reservoir is 28m and the depth at maximal draw down is 15m from bed of reservoir (13m of water can be drawn down)*

Table 3.1b: Characteristics of impoundment and / or cascade system

System description[1]		
Characteristics of Impoundment[2]	Impoundment 1	Information Source
Type of Impoundment[3]		
Use of Impoundment[4]		
Land use in the catchment[5]		
Conservation status[6]		
Comments on upstream water course[7]		
Comments on downstream water course[8]		

1 Suggestions: single impoundment; a cascade system (characteristics to be scoped per unit, add tables of columns as preferred).

2 Suggestions provided per characteristic, lists are not exhaustive and multiple options may be selected per characteristic.

3 Suggestions: hydropower on-line, hydropower offline; Water supply; in-channel storage; level/flow regulation; pumped storage (see also Conceptual models, VOLUME 2, appendix 6).

4 Suggestions: irrigation; navigation; disused; industrial; winter storage; compensation flows; swimming; fishing; rafting etc.

5 Suggestions: Pastureland; agriculture; flood storage; urban development; nature conservation; recreation; forestry etc.

6 Suggestions: SSSI's, SAC's; SPA's; RAMSAR sites; Wildlife countryside act; local nature reserves.

7, 8 Suggestions: channelled; developed flood plains; scoured; deepened etc

3.5 STEP 2: Identification of current WFD waterbody status

The second step in the process is to collate data relating to the current status of the impoundment and the adjacent upstream and downstream watercourses.

Information regarding identified pressures and impacts in water bodies has been assembled by the agencies during their characterisation process one of the first stages of WFD implementation). This process involved the identification of water bodies and their physical characteristics and the identification of protected areas as well as an assessment of the pressures and impacts (for example see SEPA, 2004), The pressures and impacts identified during this process are detailed below and further information about this process can be found on the websites of EA, SEPA or EHD as appropriate, but it may be easier to use the contacts given in Appendix 13, VOLUME 2.

Table 3.2 should be completed to record the identified pressures for the impoundment system under consideration, together with the risk category from the characterisation process.

Table 3.2. Identified pressures on water body / water bodies

Pressure	Impoundment 1	Impoundment 2	Impoundment 3
Waterbody ID			
Modified (yes/no)			
Artificial (yes/no)			
Point source pollution			
Diffuse source pollution			
Abstraction			
Flow regulation			
Morphological alteration			
Alien species			
Risk category			

This information will identify if the water body being considered is or is not at risk of meeting the Water Framework Directive's environmental objectives. There are four possible risk categories which have been agreed for the UK, based on the directive's reporting categories and these categories are detailed in Table 3.3 below.

Table 3.3: Agreed UK reporting categories

Directive reporting category	UK reporting category
At risk	(1a) Water bodies at significant risk.
	(1b) Water bodies 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.
	(2b) Water bodies not at significant risk.

Where a risk category of 1a or 1b has been assigned to the waterbody in question, the current status can be taken as failing to comply with the provisions of the WFD while a risk category of 2a will indicate that further information may be required before a determination of the current status can be made. The reasons for the failure of the water body to comply with good ecological status or potential will be identified from the pressures identified and recorded in table 3.2.

3.6 STEP 3: Identification of WFD target status

The determination of good ecological status or good ecological potential for water bodies is beyond the scope of this guidance. The topic is briefly discussed in VOLUME 2, Appendix 2). The relevant Agency should be consulted for the latest information (VOLUME 2, Appendix 13).

3.7 STEP 4: Comparison of current status of impoundment with target WFD status

Once the current ecological status and the target ecological status (GES or GEP) of the waterbody in question have been determined, the next stage in the process is to determine whether or not the requirements of the WFD are being met. This is a straight forward comparative process and the results of this process will be that either the waterbody does, or does not comply with the WFD requirements. If these requirements are not being met, then the process should continue with step 5 below.

3.8 STEP 5: Analysis of water system

The background data assembled in step 1 will be applied in this step to examine the impoundment system in significantly more detail. The objective of this step is to identify the pressures which are contributing to the current ecological status. This information will be used in step 6 to assess the need for and select appropriate mitigation measures.

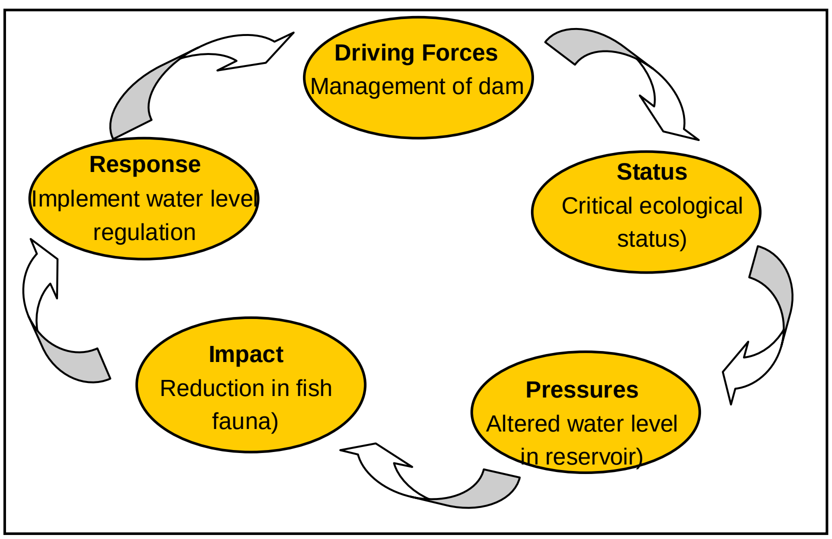
The guidance sheets in section 4, the mitigation measures table presented in the tables section, and the figures presented below are intended to help identify the potential pressures on the impoundment system being considered. Figure 3.3 identifies driving forces and pressures which apply to most impoundment situations. Figure 3.4 identifies driving forces and pressures which are specific to hydropower dams. Figure 3.5 highlights the issues which require to be considered during the assessment of cascade systems, i.e. where two or more impoundments occur in the same waterbody, or adjacent water bodies. If desired, additional information on the impacts of impoundments on a range of issues from alterations to the physical habitat and water chemistry to sediment release and recreation and the resulting ecological, physio-chemical and hydromorphological status of water bodies can be found in VOLUME 2, Appendix 3.

The table and figures have been structured according to the DPSIR model. DPSIR stands for:

- **D**riving forces (such as presence of the dam, management of the reservoir);
- **P**ressures (on the water system, for instance altered flows, eutrophication);
- **S**tatus of the water (the ecological, chemical and hydromorphological status);
- **I**mpact (deterioration of water quality in terms of ecological, chemistry or hydromorphology);
- **R**esponse (mitigation measures and management strategies).

The model is presented in Figure 3.2 and includes an example related to the management of a dam. The diagram illustrates that the selected response may also influence the driving forces within the system – e.g. removal of a significant pressure may allow another one to dominate. This coincides with the complexity of the real world systems and underlines the need for regular review.

Figure 3.2 DPSIR model



An example of the DPSIR model in practice could involve the management of the dam to meet peak demands (driving force) resulting in the drawdown of the water level within the impoundment to below 50% of the maximum level (pressure). This could result in the temporary overpopulation of the impoundment by fish (status) leading to massive fish deaths (impact). In order to mitigate against this, minimum water levels within the impoundment would require to be identified and enforced (response).

The guidance sheets, table and figures should be used along with the information gathered in step 1 to complete table 3.4 below. In order to ensure that all the potential pressures are considered, they are grouped according to the associated driving force. The table has two additional columns which should be used to record the decisions made together with comments on why each pressure is or is not considered an issue. It is likely that there will be several potential pressures which cannot be quantified as a result of a lack of information and this should be highlighted along with assumptions made as a result of knowledge of the site and expert judgement. Recommendations for further monitoring should also be noted where appropriate.

Table 3.4 Driving forces and related pressures

Driving force	Pressure	Issue Yes/no/unknown	Comments
Physical presence of dam	Loss of system continuity		
	Altered habitat		
Management of dam	Altered flow downstream		
	Change to river habitat		
	Altered water level (fluctuation) in reservoir		
	Altered residence time within reservoir		
	Release of water with altered temperature to downstream		
	Release of water with altered oxygen content to downstream		
	Release of water with heavy metal and/or nutrient contamination		
	Sediment flushing from impoundment to downstream		
	Fish entrainment into intakes (turbines)		

Management of reservoir	Engineering/ (intensive) maintenance of reservoir shoreline (beach, housing, steep shorelines etc)		
	Excavation within reservoir		
	Fish stocking		
	Recreation and boating - PAH contamination		
	General recreation		
Management of river/streams	Altered river channel meandering		
	Development of floodplains along river		
	Angling		
Management of catchment	Agricultural use / development of reservoir catchment		

The next task in Step 5 is to complete Table 3.5 for each impoundment to record whether the WFD objectives are being met and to make any comments as required. As above, there may be insufficient information to make an informed decision and if this is the case, this should be recorded along with recommendations for additional monitoring etc required.

Table 3.5 Potential impacts and issues

Potential Impacts/Issues	**WFD objectives being met? (yes/no/unknown)**		
	Impoundment 1	Impoundment 2	Comments
Ecology			
Macro-fauna			
Phytoplankton			
Macrophytes / phytobenthos			
Benthic invertebrates			
Fish fauna			
Hydromorphology			
Quantity and dynamics of flow			
Connection to groundwater bodies			
Residence time (lakes)			
River continuity			
Morphological conditions			
Physicochemical			
Temperature			
Oxygen concentration			
Nutrients			

Pollutants			
Transparency (lakes)			
Priority substance pollutants			

The desired result of this stage is a clear understanding of the characteristics of the water system, including the causes of the ecological problems.

Figure 3.3: DRIVERS (bold print) and PRESSURES (bullets) for the general impoundment situation

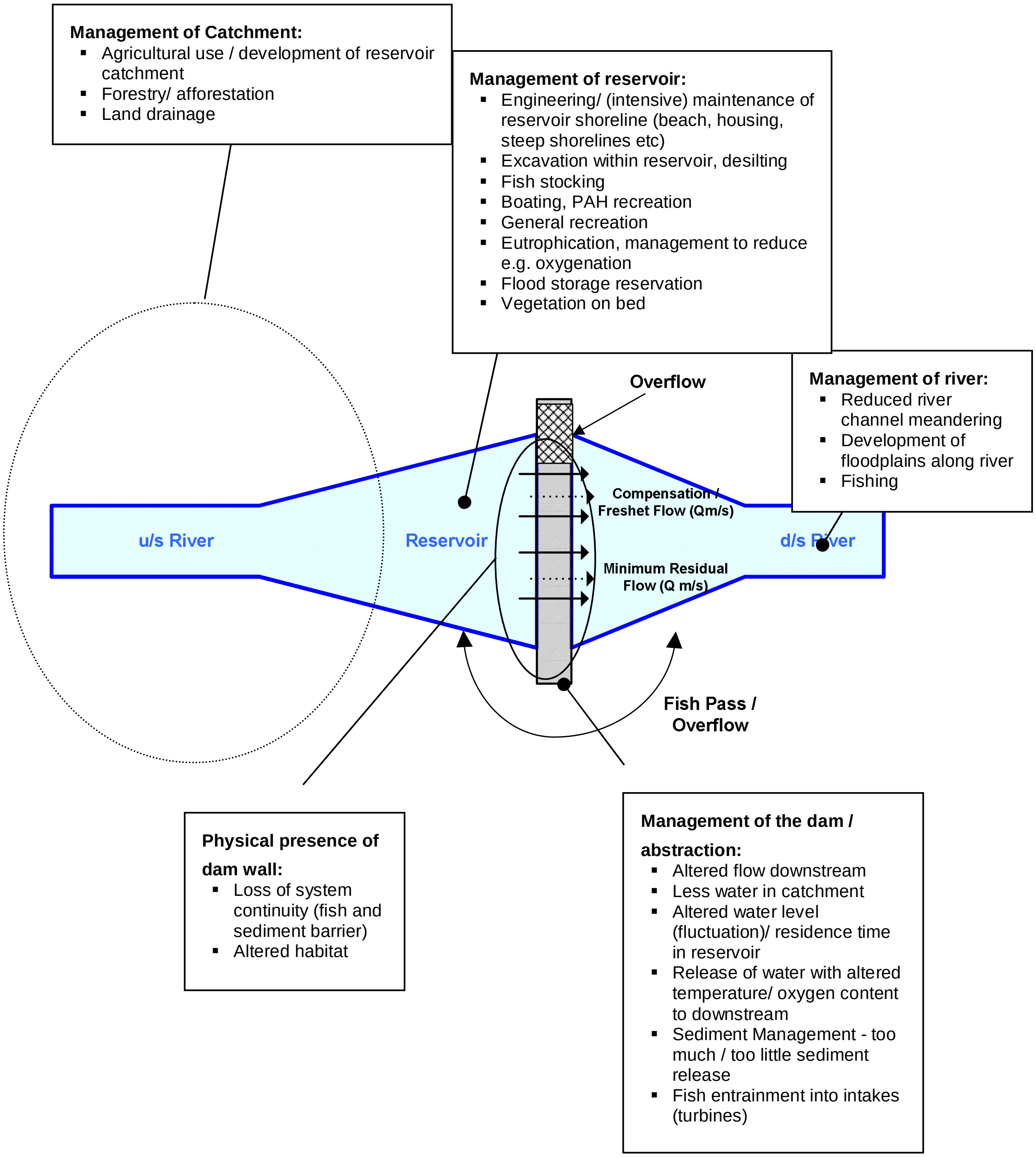
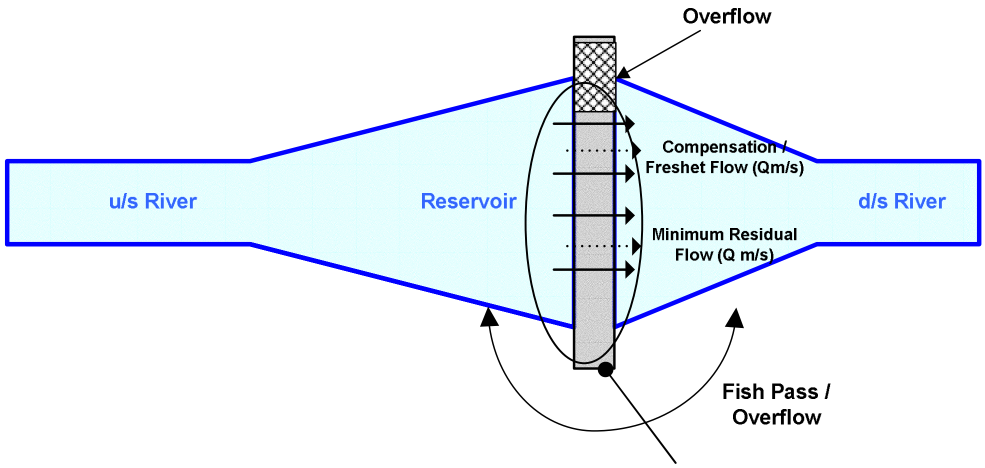


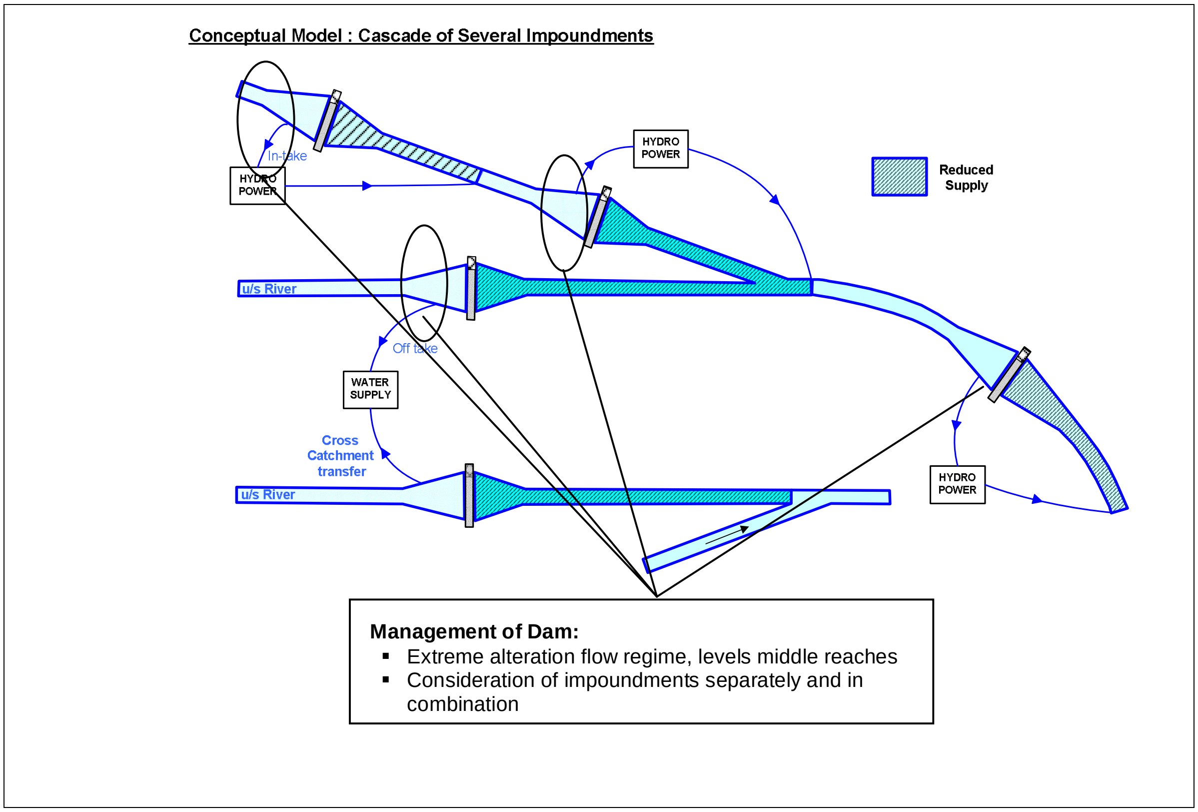
Figure 3.4: DRIVERS (bold print) and PRESSURES (bullets) specific to the hydropower situation



Management of dam:

- Hydropeaking
- Rapid and frequent drawdown and rise
- Fish entrainment into intakes (turbines)
- Energy dissipation in stilling basin

Figure 3.5: DRIVERS and PRESSURES specific to cascade systems



3.9 STEP 6: Identification of potential mitigation measures based on effectiveness

Once the water system has been characterised and driving forces and pressures on the system have been identified, consideration can be given to the potential measures which could be implemented to mitigate specific impacts on the water system being examined to ensure that the waterbody meets the requirements of the WFD.

This process can be sub-divided into three sub-steps:

– 6a: Identification of potential mitigation measures;
– 6b: Assessment of their effectiveness of mitigation against the impacts; and
– 6c: Determination of timescale for effectiveness to be observed.

Step 6a: Identification of potential mitigation measures

The first sub-step is to identify potential mitigation measures which could be implemented to mitigate against the specific impacts noted. Figures 3.6 to 3.8 illustrate which mitigation measures address the drivers and pressures for particular impoundment situations. Each measure has a unique identifier which can be used to link to the relevant entry in the mitigation measures table (Table 1) in the Tables Section of VOLUME 1. This table details a range of possible mitigation measures which are classified according to the driving forces, pressures and impacts they aim to mitigate.

The guidance sheets in section 4 list and discuss which potential solutions or measures can be used to mitigate the impacts for the environmental or management issue being addressed. Like the figures below, each measure has a unique identifier which can be used to link to the relevant entry in the mitigation table (Tables Section). The table is not exhaustive and is only intended as a resource. Other measures can and should be considered and tried as fitting. Local knowledge and expert judgement only contribute for the identification of the most suitable measures.

Using the figures, table and guidance sheets mentioned above as well as the knowledge and experience of the assembled experts, stakeholders and impoundment operators, potential measures which mitigate the pressures identified in step 5 can be identified. When selecting the measures, impacts on existing natural habitat (SSSI's etc) and other uses of the impoundment and downstream should be considered (Section 4 of VOLUME 1 and VOLUME 2). This step will deliver the best result if the selection process is approached with an open mind and consultation between the different parties involved with room for discussion and new ideas.

Step 6b: Assessment of effectiveness of mitigation measures

The second sub-step is to assess the effectiveness of the potential measures in mitigating effects on the biological elements of the WFD. Information relating to the effectiveness of each mitigation measure is given in the mitigation measures table (Table 1) in the Tables section of VOLUME 1.

Using the mitigation measures table and experience of the assembled experts from both agencies and impoundment operators an estimate needs to be made of the effectiveness of each of the potential mitigation measures for the specific situation under consideration. Because the effectiveness is difficult to quantify, we suggest using a relative scale as presented in Table 3.6a.

Table 3.6a Presentation of effectiveness of individual measures

Effectiveness of single measures	
Effect per biological element	Presentation
strong positive effect moderate positive effect	+++ ++
limited positive effect	+
no effect	~
Negative effect	-

6c: Determination of timescale for effectiveness to be observed

The third sub-step is to estimate when the measure might take effect (before 2015, between 2015 and 2021, between 2021 and 2027 and after 2027), in accordance with the requirements of the Directive. The timescale is then used as a further way to rank effectiveness. Table 3.6b demonstrates how this should be done for each mitigation measure selected. The timescale depends on the year of implementation as well as the measure itself: i.e. the measure may deliver direct results, or these results may be observed gradually over time.

Table 3.6b Criteria for evaluating the likelihood of <u>single measures</u> realising the WFD target

Expected period for realisation full effect	**Likelihood that the WFD target is realised in 2015**	**Presentation**
before 2015	Very likely	+++
Between 2015 and 2021	Likely	++
Between 2021 and 2027	Maybe	+
After 2027	Not clear	~
	Unlikely	-

The result of these three sub-steps of step 6 is a list of potential measures that could contribute to meeting the WFD target.

For ease of information and as a means of providing a record of the decisions made, the following table (Table 3.7) has been produced and should be used during the determination period using the unique mitigation measure numbers from the mitigation measures spreadsheet and the presentation information in tables 3.6a and 3.6b above. Recording the pressure each measure would mitigate will assist the next step in the process.

Table 3.7. Potential mitigation measures, indicating effectiveness and period for improvement

Mitigation measure	Effectiveness per biological element				Period for improvement
	Phyto-plankton	Macrophytes and phytobe	Benthic invertebrates	Fish fauna	
Example: provide freshets (measure 19 in table section 5)	++	++	++	++	+++ (if implemented before 2008)

Figure 3.6. MITIGATION MEASURES for the general impoundment situation

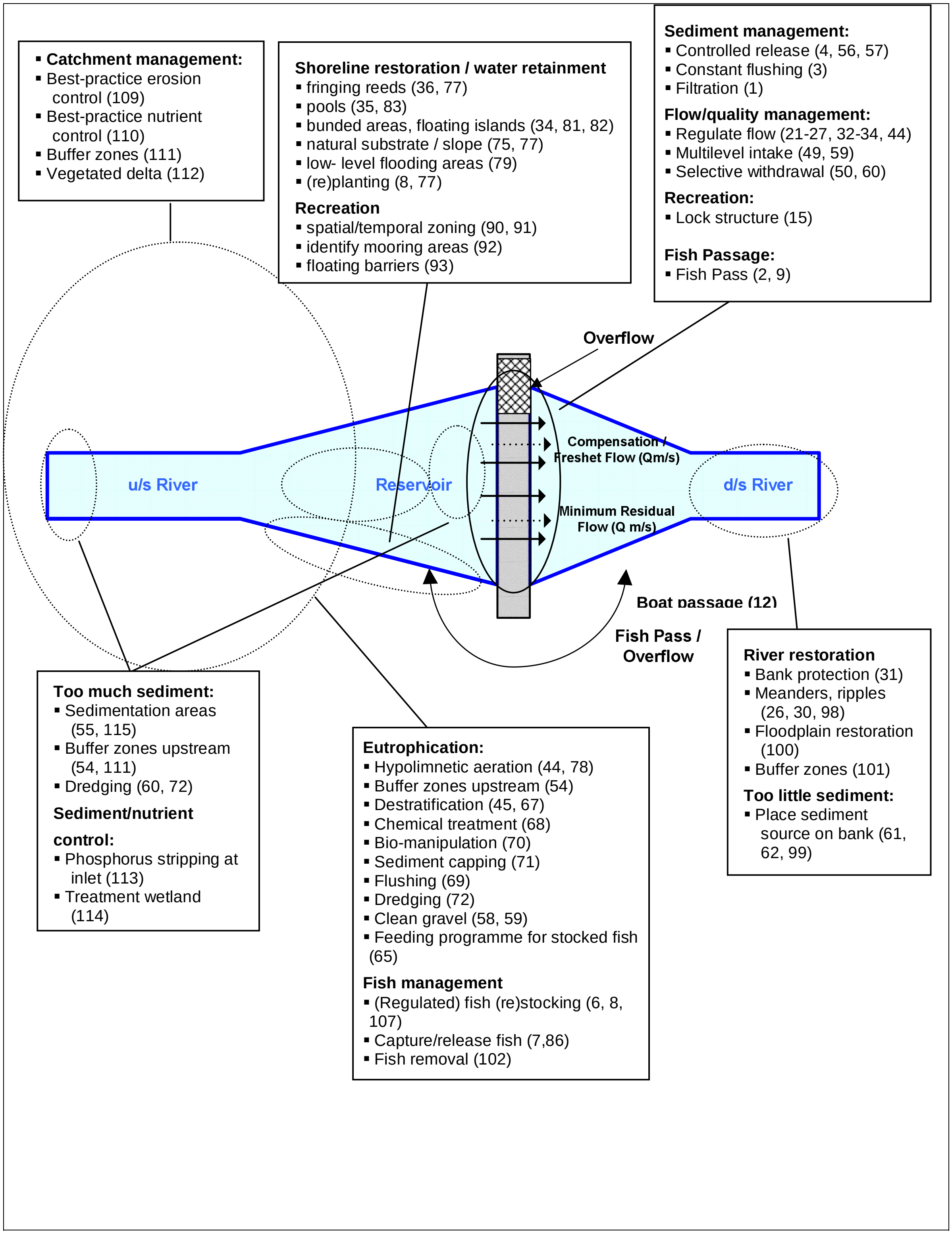


Figure 3.7. MITIGATION MEASURES specific to the hydropower situation

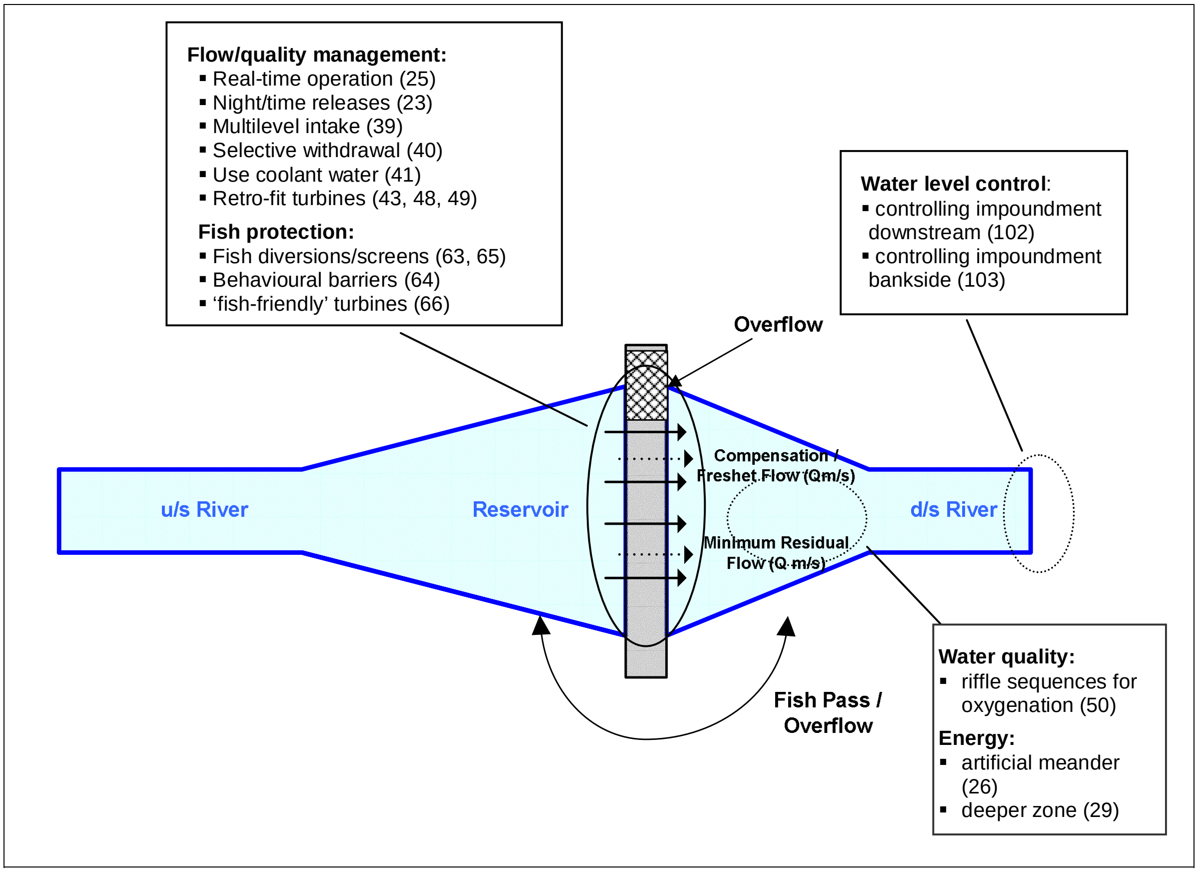
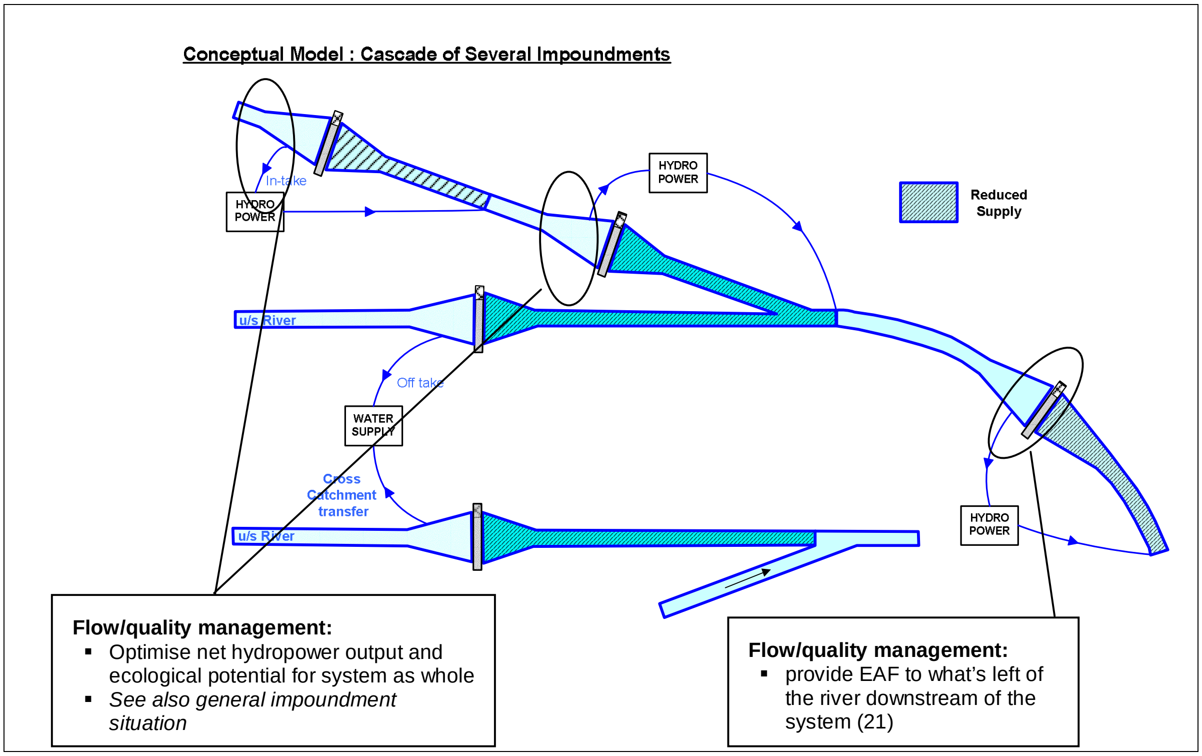


Figure 3.8. MITIGATION MEASURES specific to cascade systems



3.10 STEP 7: Identification of suitable combinations of measures

After the assessment of the effectiveness of each of the potential mitigation measures in meeting each WFD objective, various combinations of measures should then be considered in order to ensure that objectives of the WFD can be realised. Interactions between measures should be taken into account as individual measures can strengthen or weaken the effects of other measures. The effectiveness of combinations is difficult to quantify and is also case-specific. For this reason, the process of identifying suitable combinations of measures must involve specialists who are familiar with the particular impoundment system and freshwater ecosystems in general. To ensure that all the issues have been considered this step must also involve considerable discussion between the agency, impoundment managers and stakeholders.

To assist in the selection process and estimating effectiveness, the ten guidance sheets in Section 4 discuss some of the main interactions between the relevant mitigation measures and should be referred to during this step.

When considering each potential combination, the probability of the combination of measures realising the WFD objectives in the timescales required can be indicated and presented in a similar way to that used to assess the effectiveness of single measures as shown in Tables 3.8a, 3.8b and 3.8c below.

Table 3.8a Presentation effectiveness combinations of measures

Effectiveness of single measures	
Effect per biological element	Presentation
strong positive effect moderate positive effect	+++ ++
limited positive effect	+
no effect	~
Negative effect	-

Table 3.8b Criteria for evaluating the likelihood of <u>combination of measures</u> realising the WFD target

Expected period for realisation full effect	**Likelihood that the WFD target is realised in 2015**	**Presentation**
before 2015	Very likely	+++
Between 2015 and 2021	Likely	++
Between 2021 and 2027	Maybe	+
After 2027	Not clear	~
	Unlikely	-

The effectiveness of a combination of measures must be used along with the period in which the effect is expected to estimate the chance of realising the WFD target status by 2015. The table below provides guidelines, but expert judgement and consultation with specialists and impoundment managers should be involved in the process.

Table 3.8c Criteria for evaluating the likelihood of <u>single measures</u> realising the WFD target

Effectiveness combination of measures	**Expected period for realisation full effect**	**Likelihood that the WFD target is realised in 2015**	
		Chance	Presentation
strong positive effect	before 2015	Very likely	+++
moderate positive effect	Between 2015 and 2021	Likely	++
limited positive effect	Between 2021 and 2027	Maybe	+
no effect	After 2027	Not clear	~
Negative effect		Unlikely	-

The outcome of this step is a number of possible combinations of measures that can be taken to realise the objectives of the WFD *in total* with a high probability and this information can be displayed in the format detailed in Table 3.9 below which has been completed with data from a hypothetical situation for ease of understanding. In this table, each potential combination of measures is assigned a unique identifier (C1, C2 etc). The measures should have and been identified in step 6 and recorded in table 3.7 above. The effectiveness of each combination in meeting the WFD objectives should be recorded as should the timescales for achievement of the objectives. Finally, the likelihood of each combination of measured reaching the WFD objectives by 2015 should be recorded for each combination.

Table 3.9: Potential combinations of mitigation measures (example)

Combination	Mitigation measures	Effectiveness	Period for improvement	Chance of realising WFD aim
C1	1, 5, 10	strong positive effect	Between 2015 and 2021	+
C2	3, 5, 12	moderate positive effect	Before 2015	++
C3	4, 5, 13	limited positive effect	Between 2015 and 2021	-

3.11 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic impacts need to be identified. Impacts on existing natural habitat and other uses of the reservoir, catchment and up- and downstream (recreation, flood control etc) should have been considered when selecting the measures in step 6. They should also be brought into scope again in this step because they can be important and help in deciding which combination of measures to choose when:

- two or more (combinations of) measures turn out to be very close regarding their calculated (financial) cost effectiveness;
- the impacts on these related issues are large, in which case water managers may have a potential argument to request derogation from the WFD for a particular water system or the selected (combination of) measures should be re-evaluated.

This step applies the methodology for calculating cost-effectiveness. Further more detailed information relating to this issue can be found in VOLUME 2, Appendix 7.

When analysing the ***financial costs***, both the investment costs and the operational costs should be considered as a measure with high investment costs but low operational costs can be more attractive than a measure with low investments costs and high operational costs. When considering the operational costs, the lifetime of the measure should be determined and incorporated.

With this information, the Net Present Value (NPV) of the investment can be calculated for a base year. The NPV is the value of the total costs of a measure, calculated at the price level of a specific base year. In this way, costs of different (combinations of) measures become comparable.

The financial costs can usually be obtained from providers of services or materials. They can also often be calculated with sufficient accuracy based on unit costs of standard services or components. This preliminary guidance document includes a costing table (Tables Section) which provides an overview of some of the costs but the most accurate method for calculating costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. Costs are usually expressed in unit costs ((per m, m^2 or ha, m^3 or per work) with a minimum/maximum price.

In many cases it will not be possible to accurately calculate the costs of a particular mitigation measure or a combination of mitigation measures. In these instances, discussion with impoundment managers, Agency staff and other experts should enable an informed decision to be made about the costs of particular measures or at least to compare the costs of one set of measures with another (see step 9 below)

Besides financial costs, ***other costs, including socio-economic*** have to be included in the analysis. These costs could for instance be related to:

- restrictions placed on access to the water system and its catchment area, and the resulting loss of tourist revenue;
- production losses to farmers if their farming methods, e.g. use of inputs such as fertiliser, pesticides, etc. is restricted to reduce nutrient inputs;
- reduced fishery opportunities for both commercial and leisure fishermen.

In the costings table (Tables Section) some information is included regarding the financial and other socio-economic costs. However, this information is general in nature and again, discussions between agency staff and impoundment managers where local knowledge is pooled will enable the most financially sound decisions to be made. In order to determine costs and other effects in detail, it will be crucial to use local knowledge and experience. In addition it should be accepted that this assessment will be qualitative rather than quantitative, but should still be supported through expert opinion at this stage.

The outcome of this step is an overview of the financial costs (in terms of the Net Present Value) and the expected socio-economic costs for each combination of measures which can be represented in tabular form as shown in Table 3.10 below.

The results of this step should be evaluated before progressing to step 9. If the financial or socio-economic costs are too expensive, are excessive in relation to the effectiveness in reaching the target WFD status or are not sufficiently effective in meeting the WFD target status, the user should go back to step 6 or 7.

Table 3.10: Identifying financial costs and other socio-economic effects (example)

Nr.	Combination of measures	Net Present Value	Other socio-economic effects
C1	Combination of M1, M5, M10	£350 000	Negative effect on recreation
C2	Combination of M3, M5, M12	£400 000	No other effects
C3	Combination of M4, M5, M13	£300 000	Negative effect employment

3.12 STEP 9: Ranking of combinations according to cost-effectiveness

Having completed steps 1 through 8, the combinations of measures can now be ranked according to cost-effectiveness (financial costs vs. effectiveness in reaching target WFD status as defined for 4 biological elements). This can be done with help of a scheme as presented in Table 3.11. The table collates the information from steps 7 and 8 and shows that the ranking of cost-effectiveness is based on the chance to reach the WFD-aim, the financial costs of the combination of measures (Net Present Value) and the other expected socio-economic effects.

Table 3.11. Selecting the most cost-effective combination of measures (example)

Selecting the most cost-effective combination of measures							
Nr.	Combination of measures	Likelihood of reaching WFD target			Net Present Value	Other socio-economic effects	Ranking of measures based on cost-effectiveness
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	Combination of M1, M5, M10	strong positive effect	Between 2015 and 2021	+	350.000 Pound	Negative effect on recreation	2
C2	Combination of M3, M5, M12	moderate positive effect	Before 2015	++	400.000 Pound	No other effects	1
C3	Combination of M4, M5, M13	limited positive effect	Between 2015 and 2021	-	300.000 Pound	Negative effect employment	3

The outcome of this step is a ranking of each of the options to determine the most suited combination of measures. It should be noted that this ranking is based on the judgement of those making the decision. Following the steps in the guidance document ensures that the decision-making moves towards making sound judgements, and leads to outcomes that are technically sound.

3.13 STEP 10: Selection of most cost-effective combination of measures

With the help of the information as given in step 9 and the available expert knowledge and experience, the most cost-effective combination of measures can be selected. It should be reiterated that the indirect effects of the measures will be based on a qualitative assessment and will be site specific and require expert and local judgement.

As in step 9, if the financial or socio-economic costs are too expensive, are excessive in relation to the effectiveness in reaching the target WFD status or are not sufficiently effective in meeting the WFD target status, the user should go back to step 6 or 7. As discussed in step 11, water managers also can use the result of step 9 as an argument to request derogation from the WFD for a particular water system. It is likely that in some situations the costs of implementing the mitigation measures required to fulfil the requirements of the WFD may be disproportionate to the ecological benefits they would bring and in this instances the process which has been undertaken will form the basis for the submission to the European Commission for derogation under the provisions of Article 4(7)(c) of WFD.

3.14 STEP 11: Identification of actions to be taken to comply with WFD

The final step in the process is to determine which actions should be taken in order to ensure compliance with the provisions of the WFD. This could involve the determination of the conditions to be included in the licence to be granted by the relevant agency for the impoundment(s) in question and the associated improvement works to be undertaken by the impoundment manager. If several mitigation measures require to be implemented, an agreed timescale for implementation to ensure that the most effective measures are implemented first may be necessary.

Any decisions relating to actions requiring to be taken to comply with the WFD will require integration into the River Basin Catchment Management Plans and will therefore require liaison between the licensing agencies and those responsible to the delivering of the River Basin Catchment Management Plans.

4 GUIDANCE SHEETS FOR KEY ENVIRONMENTAL AND MANAGEMENT ISSUES FACING IMPOUNDMENT MANAGEMENT

4.1 Introduction

Based on challenges facing impoundment management in the UK, the main environmental and management issues have been identified. For each of the key issues, a guidance sheet has been developed:

SHEET ISSUE

1. Hydro-peaking Flows
2. Altered Flow Regime
3. Extreme Water Level Fluctuation in the Littoral Zone
4. Littoral Zone Development, Engineering and Maintenance in the Impoundment
5. Eutrophication
6. Alterations to Water Chemistry, Temperature and Oxygen Levels in the Impoundment and Downstream
7. Migration Barrier
8. Fish Damage / Kills Due to Entrainment
9. Sediment Management
10. Recreation

The guidance sheets are intended as a supplementary tool in identifying pressures affecting the biological status of a particular impoundment, and, used together with the step-by-step approach presented in section 3, in selecting the most appropriate (combination of) mitigation measures.

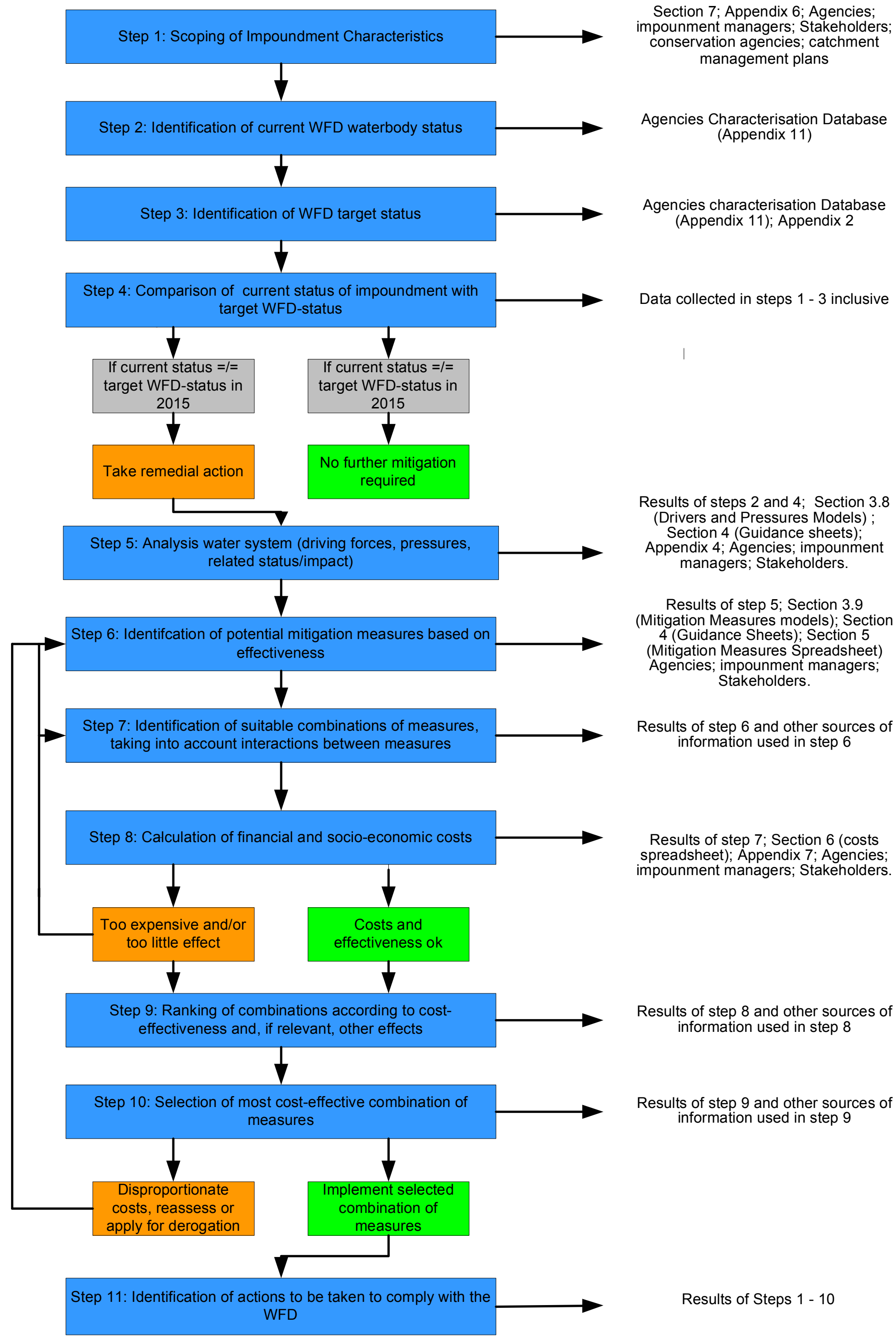
The Technical Appendices in Volume 2 provide further information and background on the potential effects of each of the environmental and management issues listed above on the WFD biological elements of phytoplankton, vegetation, invertebrates and fish.

4.2 Structure of the Guidance sheets

The guidance sheets have been structured to mirror the step-by-step approach to selecting the most appropriate (combination of) mitigation measures provided in section 3 of this report. The flow chart which summarises the approach is presented again for ease of reference (Figure 4.1)

Steps 1 through 4, 10 and 11 are generic. To keep the guidance sheets as succinct as possible, these steps are only presented and discussed once, in section 4.3.

Figure 4.1 Flow chart showing the 11 steps in the step by step approach



The remaining steps (steps 5 through 11) are more specific to each environmental and management issue, and are therefore discussed per guidance sheet. Each guidance sheet consequently includes:

- a brief introduction to the issue;
- a short analysis of the likely driving forces, pressures, related impact and status of the water system related to the particular guidance sheet issue (corresponds to STEP 5 of step-by-step approach)[1].
- a listing of the potential mitigation measures for the particular guidance sheet issue, cross-referenced to the Mitigation Measures and Management Strategies in the tables section of this report (corresponds to STEP 6 of step-by-step approach).
- a box discussing the mitigation measures, with recommendations for which (combinations of) measures are most suitable in particular situations for achieving target ecological status.
- potential combinations of measures (corresponds to STEP 7 of step-by-step approach).
- a discussion of the financial costs of the measures, the socio-economic effects and other topics related to the particular guidance sheet issue (corresponds to STEP 8 of step-by-step approach). Expected input data requirements prior to implementing mitigation measures and monitoring requirements for measuring effectiveness after implementation are provided. Key stakeholders to consult are also named.
- a tool for the ranking of the most appropriate mitigation measures for a site specific location is provided (corresponds to STEP 9 of step-by-step approach).

Key to the Guidance Sheets:

(***21***)	Reference number for mitigation technique (as presented on the Mitigation Measures and Management Strategies table, included in tables section of this report)	
(Sheet 5)	Refers to Guidance Sheet which discusses this issue or measure in more detail	
Group 1	Stakeholders are grouped according to the following criteria:	
	Group 1	Water quality / water resources regulators / licensing bodies (SEPA, EA)
	Group 2	Impoundment manager / operator / designer / consultant
	Group 3	Flood defence / drainage bodies (Regional Councils in Scotland, EA, Internal Drainage Boards, local councils)
	Group 4	Statutory nature conservation agencies (SNH, EN, and CCW) Non-statutory nature conservation agencies (wildlife trusts, RSPB, WWF, fishery boards / trusts etc.)
	Group 5	Riparian owners, owners of the fishing rights
	Group 6	Recreational Groups – boating / canoe clubs, angling clubs, ramblers etc.

[1] Step 1 (measuring the current ecological status) is assumed to have been carried out at this stage by the WFD implementation agencies, resulting in the conclusion that measures need to be taken to achieve the target WFD-status

4.3 Applying steps 1 through 4, 10 and 11 of step by step approach to main environmental and management issues

4.3.1 STEP 1: Scoping of impoundment characteristics

The objective of this step is to collate general information on the characteristics of the impoundment(s) which will be used in following steps of the process. Section 3.1 of this report describes which information should be collected. Information on impoundment type (hydropower, drinking water, etc) and environmental and management issues (eutrophication, etc) can be relevant in determining which guidance sheets are potentially relevant. The information will also be used to identify pressures (step 5) and potential mitigation measures (step 6), and other issues which need to be considered, such as socio-economic costs and existing designated sites and protected species (SSSI's etc).

4.3.2 STEP 2: Identification of Current Waterbody Status

In order to determine whether the current status of a waterbody meets the WFD objectives (STEP 4), data must be collected on the WFD biological, physico-chemical and hydromorphological elements. As mentioned in section 3, guidance information for assessments of impoundments can be found on the Agencies web sites. As the exact location of this information on the websites change, the local agency office should be contacted for up to date information (see appendix 11, Volume 2 for contacts).

4.3.3 STEP 3: Identify Water Framework Directive Target Status

The determination of good ecological status (GES) or good ecological potential (GEP) for water bodies is beyond the scope of this guidance. The topic is briefly discussed in appendix 2, Volume 2. The relevant Agency should be consulted for the latest information (appendix 10, Volume 2).

In the guidance sheets, potential (combinations of) measures for mitigating pressures in order to achieve the target WFD status (GES or GEP) are provided.

4.3.4 STEP 4: Compare current and desired ecological status

Once the current ecological status and the target ecological status (GES or GEP) of the water body in question have been determined, the next stage in the process is to determine whether or not the requirements of the WFD are being met. This is a straight forward comparative process and the results of this process will be that either the waterbody does, or does not comply with the WFD requirements. If these requirements are not being met, then the process should continue with step 5 below.

The different guidance sheets discuss how the environmental and management issues impact the current status, and how these can be mitigated.

4.3.5 STEP 5 to STEP 9 inclusive

These steps are ISSUE SPECIFIC, and the relevant GUIDANCE SHEETS should be referred to for detailed information.

4.3.6 STEP 10: Select most appropriate combination of measures

With help of the information from step 9 and the available expert knowledge and experience, the most appropriate combination of measures for a particular site can be selected. For the issues addressed in the guidance sheets, the information and recommendations included in the boxes can be useful for selecting the most appropriate (combinations of) measures.

The wider effects such as impact on recreation and flood management (see section 5 of this report) will also need to be considered. Site specific data collation and analysis and expert opinion are a must.

As discussed in section 3 of this report, if the financial or socio-economic costs are too expensive, disproportionate to the effectiveness in reaching the target WFD status or not sufficiently effective in meeting the WFD target status, the user should go back to step 6 or 7. Alternatively, water managers also can use the results of step 9 as an argument to request derogation from the WFD for a particular water system.

4.3.7 STEP 11: Actions necessary to comply with the WFD

As stated in section 3 of this report, the last step is to determine which actions should be taken in order to ensure compliance with the provisions of the water framework directive.

This can involve (additional) monitoring, liaising with key stakeholders, modelling studies or structural and/or changed water management. In some cases, derogation may need to be requested.

If several mitigation measures require to be implemented, an agreed timescale for implementation to ensure that the most effective measures are implemented first may be necessary.

4.4 GUIDANCE SHEET 1: HYDRO-PEAKING FLOWS

4.4.1 Introduction

This guidance sheet is relevant to hydropower reservoirs.

Ecological problems can arise in hydropower reservoirs as a result of sudden changes in flows downstream of the dam caused by the operation of the hydropower system. Fish, macrophytes, and macrofauna experience the strongest negative impact. As a result, the target ecological state may not be achieved by 2015.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this section as succinct as possible, these are discussed once in section 4.3.

4.4.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s):
- Physical presence of the dam
- Management of the dam
- Management of the river

Pressures:
- Loss of continuity
- Altered flow downstream
- Sediment management - too much sediment
- Sediment management – too little sediment
- Altered river channel meandering

Status and Impact:
- Critical ecological status, related to the following impacts:
- Stranding of invertebrates and fish
- Disturbance to all biota
- Loss of in-stream habitat

4.4.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Altering the shape of the discharge curve (see Sheet 2)

- Basic compensation flow (17)
- Minimum-maximum flow rates (18)
- Environmentally acceptable flow rates (21)
- Seasonally variable flows combined with environmentally acceptable flows (22)
- Ramping up and down of releases (16)
- Consider time of day / night for releases (23)
- Real-time operation to meet the water demands of biological elements (primarily fish) downstream (25)

Miscellaneous

- Using multi-stage channels (28)
- Providing a controlling impoundment downstream (102)
- Providing a controlling impoundment on the bankside (103)
- Increase reservoir capacity (117)
- Providing flow refugia (105)
- Contingency planning for emergency draw-down (118)

Dissipating discharge energy directly downstream (however, this does not prevent depth changes in the river which are key)

- Artificial meander (30, 98)
- Deeper water directly downstream (27)

Box 1 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7 (Section 4.4.4).

Box 1: Discussion:

Stranding is caused by the rapid reduction in stream stage (depth) when power production ceases (Moog, 1993). Studies in North America suggest rates of water level decline to minimise stranding by salmonids range from 2.5-6cm/hour (Hunter, 1992; Bradford et al., 1995). The effectiveness of applying these rates is not known for UK species. Applying these rates would not minimise the disturbance to organisms during the rapid increase in flow at the start of power production. There was no information available to this study on the impact of rapidly increasing hydro flows but experimental work on invertebrates would suggest sudden disturbance of the sediment can displace large numbers of animals (Boulton et al., 1992; Death, 1996a; Death, 1996b).

Although, to our knowledge, not used in the UK to mitigate impacts of hydropower function, two or multi-stage channels (28) could be used, in theory, to provide a range of habitats at both base flow and during hydro-peak flows. This approach to habitat provision is likely to be limited to occasions where hydro-peak flows occur for considerable periods of time; e.g. order of days and weeks rather than hours. Its impact on territorial fish like salmonids would need to be investigated before application.

The use of an environmentally acceptable compensation flow (21) (further discussed in Sheet 2) as advocated for all impoundments in this report, has proved capable of providing additional habitat for fish in systems subject to hydropower fluctuations, (Gibbins & Acornley, 2000). Raising and / or lowering the flows gradually is also used to reduce the impact of stranding (16), where compatible with the hydropower regime and where flexible release mechanisms are in place.

A controlling impoundment (102), downstream of the hydro-generation point could be used to receive hydro-peak flows and control their release further downstream, basically acting as a valve on the system. This has the advantage of potentially allowing un-interrupted hydro-power generation while allow the provision of environmentally acceptable flows. The cost is a sacrificial section of channel between the hydropower impoundment and the controlling impoundment. The negative affect is that the controlling impoundment can result in over-moderation of the flows, such that naturally variable flows (which are desirable for scouring and benefit some species) are rare.

In Austria bank side reservoirs (103) have been used to provide additional releases to help dampen the effect of hydropeak flows and thereby reduce the rate of water level drop (Moog, 1993). Studies on Atlantic salmon and brown trout suggest stranding occurs less frequently at night (Saltveit et al., 2001) (23).

In Scotland discharge of hydro-schemes to lochs rather than rivers commonly occurs. The impact of this is not known but thought to be minimal compared to the damage to riverine systems. Any impact will be related to the Volume of water released compared to the Volume of the receiving loch (see Sheet 3) and differences in water chemistry/temperature between supply and receiving waters (see Sheet 6).

Hydropower systems are designed to be operated to maximise the use of the water resources at high head upstream. The operation of the dam is therefore carefully controlled to meet the power production requirements. The ability to manage water resources can be improved at the design stage, through provision of extra capacity within the reservoir and the design of flexible flow mechanisms (see Section 5.2.1 - Design Phase). Contingency planning for emergency situations (such as draw-down due to concerns over dam safety) should be in place in order to minimise adverse impacts on WFD biological elements wherever practical (118).

Recommendations based on effectiveness for achieving target ecological status:
For existing schemes, a basic compensation flow Q90/95 (17) could be required initially then replaced with a modelled Environmentally Acceptable Flow (21). This may require moderation of the flow during hydropower working and greater release when the hydropower is not working.

Where ever possible releases should be ramped up and down to limit the impact of stranding (16). This requires a flexible release mechanism.

Consideration should be given to generating power at night in preference to the day, where ecological benefits can be demonstrated (23)

On new schemes a controlling impoundment downstream (102) should be considered to allow pulse releases to be captured and released in an ecologically acceptable manner. Alternatively the use of bankside impoundments should be considered to help mediate flow (103). The flow release from the controlling impoundment should aim to meet the environmental needs downstream wherever possible, making use of any additional design capacity. Seasonal low flow conditions are, however, part of a natural, unregulated system and their benefits should be recognised.

Recommendations for management
For existing hydropower dams, implementation of basic compensation flow is the minimum flow regulation measure in terms of costs and effectiveness. Environmentally acceptable flows are likely to be more expensive because they require more (preliminary) research and more complex modelling, but are likely to be more effective for meeting the WFD objectives for rivers. There is therefore a need for clearer guidance and/or research and development of generic minimum compensation flows for different types of habitat.

For new schemes, choice between EAF or controlling impoundment depends on results of the cost-benefit analysis (step 9 and 10).

4.4.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 1 can be useful in this step.

A number of example combinations have been provided in Table 4.1 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.1: Potential combinations of mitigation measures presented using unique reference in the mitigation measures table in the Tables section of this report.

Combination	Objective Achieved	Mitigation measures*				
		1	2	3	4	5
Example C1	*A reduction in non-natural hydro-peaking flows*	*21(Provide environmentally acceptable flows (imitate natural flow regime)*	*16 (Raise and lower flow rates gradually (to avoid hydropeaking type flows changes)*			
Example C2		*25 (Real-time operation to meet water demands of biological elements (primarily fish) downstream)*	*102 (Provide a controlling impoundment do*			

			wn stre am)			
C3						
C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.4.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

A general conclusion is that combinations with measures with high (technical) investment costs, such as building an additional impoundment (***102, 103*****)** will be more expensive than those which only involve modifying water release management to alter the shape of the discharge curve (***16-18, 21-23, 25***).

Other issues to be considered

- flood control (see Section 5.3 – sustainable flood management)
- recreational use of the river (see Sheet 10)
- altered flow regime (see Sheet 2)
- fish migration (see Sheet 7)
- water level fluctuations in the impoundment littoral zone (see Sheet 3)

Controlling impoundments (***102, 103***) and multi-stage channels (***28***) offer additional potential for use in flood control. In addition, the effect of proposed changes in flow regime on flooding risk upstream and downstream must be thoroughly investigated before implementation (see Section 5.3 – sustainable flood risk management)

Hydropower releases from dams can be scheduled to accommodate the needs of canoeists and rafters as well as fish and wildlife (***97***). For example, the St. Louis Hydropower project (United States) license includes provisions for periodic whitewater flow releases into a by-pass of the natural river. The releases are scheduled for peak recreational periods, and are tailored to the skills of white-water rafters and canoeists. Release schedules are made available to the public via recorded phone messages (www.amrivers.org). Similar dam released white-water schemes are promoted in the UK, for example on the River Tryweryn (Wales) and Rivers Tay (Grandtulley and Stanley), Tummel and Orchy in Scotland (www.blueskyexperiences.com) (see Sheet 10).

For the Federal Columbia River Power System (United States), a Water Management Plan (***106***) is drafted yearly to co-ordinate system operation with fish migration. The Plan covers all operation aspects, including turbine outages, power generation schedules, water temperature control, spill, total dissolved oxygen management and special operations for other uses (see Sheets 2, 6, 7 and 10).

A flow release regime that minimises extreme water level fluctuation (beyond natural variation) in the reservoir also benefits shoreline biota (***32***) (see Sheet 3).

Input data requirements:

For EAF, determine target species and collect data on the environmental needs of these species. This includes migration period, location, optimal flow rates (for different life stages), water level, water temperature, and oxygen levels.

Define the hydrological needs of the dam user (i.e. hydropower production) (optimum and minimum).

Determine the (hydrological) needs of other users (recreation, flood control, water abstraction).

The (maximum) discharge (over time) from the hydropower dam must be compared with release rates from the controlling dam to determine the size of the controlling impoundment and optimal distance between the hydropower dam and controlling impoundment in a cascade dam system. Geographical and hydrological limitations (amongst others) may, however, prevent the optimum size and distance to be achieved.

Monitoring requirements:
Record timing, flow rates, water temperature and oxygen levels after implementation of the $Q_{90/95}$ / EAF, to determine if these match the objective hydrological and physico-chemical objectives. Flow rates, substrate composition, water and oxygen levels should also be monitored downstream (as necessary) to determine if these meet the needs of target species.

Identify if species specific monitoring is required. Focus on the biological elements required under the Water Framework Directive (utilising indicator species as appropriate) and / or protected species under the Habitats Directive.

Key Stake holders:
Group 1, 2, 3, 4, 5, 6

4.4.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented overleaf (Table 4.2) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.2: Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	21,16	++	Between 2015 and 2021	+	350.000 Pound	Negative effect on recreation	2
C2	25, 102	+++	Before 2015	+++	400.000 Pound	No other effects	1
C3							

** Case-specific, only an example. See Section 3.12 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.4.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.5 GUIDANCE SHEET 2: ALTERED FLOW REGIME

4.5.1 Introduction

This guidance sheet issue can be relevant to all impoundments.

The flow regime downstream of the dam is one of the primary factors in influencing GES / GEP within the river system. Whilst river species are naturally tolerant of fluctuating flow conditions, GES / GEP will not be achievable if the tolerance limits are consistently breached for the desired biological elements.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.5.2 STEP 5: Analyse water system (driving forces, pressures, related status /impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s):

- Physical presence of the dam.
- Management of the dam.

Pressures:

- Continuity.
- Altered flow downstream.
- Change to river habitat.

Status and Impact:

- Reduced flow and loss of aquatic and wetland habitat.
- Reduced flow leading to natural features forming barriers to migrating fish.
- Loss of seasonality leading to changes in community structure.

4.5.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Manage Flow Regime:

- Set minimum and maximum flow rates (minimum compensation flows) (***17, 18***)
- Provide freshets to mimic minor natural floods and encourage upstream migration of fish (also used for recreational river use) (***19***)
- Provide flushing flows to replicate major flood events, scour algae and flush fine sediments out of spawning gravels (***20***)
- Provide Environmentally Acceptable flows (EAF) (***21***)
- Provide seasonally variable flows combined with EAF (***22***)
- Consider time of day for releases (***23***)
- Controlled spill to meet water demands of biological elements (primarily fish) downstream (***24***)
- Real-time operation to meet water demands of biological elements (primarily fish) downstream (***25***)
- Construct or manage 'Sacrificial' impoundments upstream to provide the compensation flow requirements (***104***)
- Increase reservoir capacity (***117***)
- Contingency planning (***118***)

Modify River Habitat:

- Introduce (artificial) meanders / riffles directly downstream of dam to dissipate energy (***26***)
- Introduce buffer zone of deeper water directly downstream of dam to dissipate energy (***27***)
- Create multi-stage channels (***28***)
- Undertake physical habitat modification to improve depth and velocity of existing flows downstream (***29***)
- Undertake river habitat restoration downstream (create more natural meanders, riffles etc.) (***30***)
- Provide bank protection to prevent erosion (***31***)

Box 2 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 2: Discussion

Manage Flow Regime:

There are five basic components that an EAF needs to provide:

- Suitable space
- Suitable velocity / flow
- Suitable depth
- Suitable variability
- Where possible eliminate barriers to migration

When a river is impounded space becomes reduced, the range of velocities and depths alter and the system loses its natural variability. Data on the requirements of biota for these parameters is patchy and exists mainly for fish (Johnson et al., 1995a; Johnson et al., 1995b; Souchon, 1994; Baran et al., 1995), with some work on invertebrates (Jowett et al., 1991a). There is less work on the other biological elements, neither macrophytes nor phytobenthos, are usually included in EAF assessments (***21***). There is a manual containing the depth requirements of aquatic plants in the UK (Newbold & Mountford 1997).

Given the paucity of data on biological requirements, targets have been set either using limited ecological data, expert opinion or most frustratingly no targets are set and flows are set in an arbitrary manner (Souchon et al., 1998). Despite this lack of knowledge there has also been reluctance to test the outcome of applying EAFs, e.g. of 616 Instream Flow Incremental Studies (IFIM) studies in the US, six involved monitoring, the results of which were not reported (Armour & Taylor, 1991). However some 'before and after studies' do exist and are described below (Jowett & Biggs in prep). This lack of supporting data may help to explain the enormous number of variant solutions for setting EAFs, see Jowett (1997) for a review. Below the main methods for setting EAF used are explained and a compromise solution for UK conditions suggested.

Under the WFD monitoring of condition is required and targets must be set by comparison with a reference status. That status has yet to be defined for biological elements downstream of impoundments but there is the possibility of setting site specific reference conditions. Taking these facts into consideration the assessment of EAF methodologies is described in general terms for the WFD biological elements.

The goal of finding ecological acceptable flows has lead to intense research through out the world: (Volume 2, Appendix A; and Jowett (1997)) Jowett (1997) reviews the modelling approaches taken which are based on historical flows, geometry of the channel or the habitat requirements of a target species. All these models describe a steady flow down river which is 'ecologically acceptable'; they do not consider temporal variability. For the hydraulic and habitat type models, the biological response to increased flow is thought to be non-linear, i.e. the biological response (arbitrary measures) is rapid at low flow and then slows rapidly (Jowett 1997). There is therefore an inflection point above which there is limited return for releasing increased Volumes of water

The Tennant method is a common historical flow method (Tennant, 1976). It assumes that a percentage of the mean flow is needed to provide decent habitat for fish. In a study of 11 streams in the US, Tennant also noted that there was an inflection point in the response of habitat parameters: between 0-10% of average flow, habitat parameters responded rapidly then above 10% more slowly. However despite this initial rapid increase in available habitat Tennant thought that depth and velocity parameters (average depth 0.3m, velocity 0.25m/s) were not sufficient at 10% average flow and the best compromise was to set flows at 30% average flow which achieved velocities of 0.45-0.6m/s and depths of 0.45-0.6m. The Tennant method is a low cost approach but the ecological thinking behind it is limited. The major advantage of the method is that it allows a system to retain an element of its uniqueness because it is based on historical flows. The method currently used by SEPA / EA is also based on historical flows or a modelled description of historical flows using Low Flows 2000. The compensation flow applied by SEPA / EA is the natural flow in the system which is exceeded 90% or 95% of the time. Presumably the logic is that the biota has the capacity to withstand these naturally low flows throughout the year as they have already exhibited the capacity to do so for short periods. This method does not take into account the influence of seasonal fluctuations on ecosystem function.

Hydraulic geometry methods focus on providing a fixed reduction in a hydraulic parameter, e.g. 20% reduction in wetted perimeter. It requires that field surveys of cross sections be carried out and then the hydraulic geometry can be related to discharge. By focusing on wetted perimeter, the possibility exists that adverse depths and velocities will be created. Again the ecological thinking behind it is limited. However hydraulic geometry studies can be used to determine threshold limitations to discharge which are site specific if the flow preferences of taxa are already known (Jowett, 1998). This combination of techniques may have potential in the UK.

Habitat modelling work in initially concentrated on fish (PHABSIM, Bovee 1982) but invertebrates have been investigated too (Jowett et al., 1991b). This type of work is time consuming and costly but can provide very detailed information on species requirements. Flow preference curves (depth and velocity) are derived for the species of interest from field data. Then hydraulic modelling is applied to calculate the amount of available habitat, defined using the flow preference curves, present at different discharges. There are a number of criticisms levelled at PHABSIM; firstly it is difficult to derive accurate flow preference curves. That's because fish and invertebrate species are mobile and can have different requirements at different life stages and even while exhibiting different behaviour, resting, feeding etc (Layzer & Madison, 1995). Theoretically different models may be required for each life stage. In addition making a field measurement of velocity that relates to a small benthic invertebrate is not an easy task, (O'Hare 1999).

Despite these criticisms, five out of six 'before and after' studies on the implementation of EAFs suggest the PHABSIM approach does increase the carrying capacity of a system for trout and invertebrates (Jowett & Biggs in prep). Furthermore the invertebrate community composition shifted to one which reflected the community upstream of the impoundment. The invertebrate data would suggest a shift was observed from animals characteristic of sluggish depositional flow to those typical of a more erosive fast flowing system.

The PHABSIM approach has been applied with some success in the UK; i.e. Derwent Water, (Maddock *et al* 2001) (Spence & Hickley, 2000). As our ecological understanding of the habitat preferences underlying the models improves, it will allow the development of more sophisticated and defensible models, i.e. Booker *et al* (2004).

The only direct comparison of any of the major methods was a desk study comparing the historical approach to the habitat approach. Jowett (1997) modelled the amount of available habitat in 22 rivers (median flow range 0-16m^3/s) in the North Island of New Zealand, using four common forms of required discharge;

10% Average flow (Tennant 1976)
30% Average flow (Tennant 1976)
Median flow retaining 2/3 food-producing habitat for fish
20% Weighted Usable Area (WUA) (PHABSIM approach)

The results showed that with increasing stream size habitat based assessments suggest minimum flow requirements, as a proportion of the flow decrease with increasing stream size. Minimum discharges that retained 2/3 of the food-producing habitat varied with median discharge to the power of 0.3-0.4 whilst those based on the Tennant method varied linearly with median discharge. In practice this means that on average over the range of median discharges examined, 10% average discharge did not produce 2/3 habitat retention whereas 30% of median discharge provided flow much in excess of what was need to retain 2/3 of the habitat.

As mentioned above the models do not take into account the need for temporal variability in flows. Generally seasonal variation in flow (***22***) acts as a natural disturbance in river systems breaking up successional processes and it can have a strong structuring influence on communities (Boulton et al., 1992; Dudgeon, 1993; Hildrew & Giller, 1994). Most work has been done on benthic invertebrates and experiments show that different species respond differently to disturbance. For this reason flooding as a disturbance parameter (***19, 20***) is included in most ecological models of river function. In Scotland uplands streams are ‘rithron’ (spatey / high energy) in nature and have a distinguishable invertebrate fauna adapted to spatey flow regimes (Fozzard et al., 1994). More generally it has been shown that invertebrates can be related to different types of flow regime. The LIFE scoring system for benthic invertebrates devised by the Environment Agency describes flow preferences, in the form of flow regime associated with most major benthic invertebrate taxa (Extence *et al* 1999). A system with constant compensation flows not augmented with any additional releases is likely to have exceptionally stable conditions. Under such conditions algae can build up to high levels.

Water supply reservoirs commonly fills during the summer. Winter flooding, on such systems occurs in a manner similar to a natural system because the reservoir over tops but there is no or little summer flooding so stable growing conditions prevail during the summer. Such rivers can exhibit a dense macrophyte growth and banks stabilised by riparian vegetation. For migrating fish, seasonal floods stimulate and facilitate migration upstream and spawning by providing flow over obstacles. In the UK freshets (***19***) are released to facilitate the migration of fish and on occasion to shift fines, but not to alter macrophyte or invertebrate community structure. Freshets are also released for recreational purposes, e.g. to facilitate white water rafting.

In summary, systems require a seasonal element not supplied by existing EAFs (22). Habitat based models such as PHABSIM would prove difficult to develop for all the individual taxa encompassed by the WFD. A good compromise would to be use existing PHABSIM habitat curves to choose threshold values for hydrological geometric parameters which can be applied generally.

The concept of additional 'sacrificial' impoundments (104) to store and provide the additional flows is discussed in Guidance Sheet 1. The concept of providing additional capacity within the existing reservoir (117) is also discussed in Guidance Sheet 1 and in Section 7 – design considerations.

Modify Downstream Habitat:
As an alternative, the remodelling of the stream (29) can be used as a means of diversifying flow, (Brittain & L'Abée-Lund, 1995) or multi-stage channels (28) can be used to maximise the usefulness of water that is released. Evidence would suggest that the introduction of riffle and pools (29, 30) supports increased production in channelised systems (Ebrahimnezhad & Harper, 1997) in general and downstream of impounded systems too (Fjellheim & Raddum, 1996).

There have been a number of recent guidance documents on habitat modification (29), some specifically relating to Scottish gravel bed rivers (Hoey et al 1998) and rivers in general too, (Anon, 2003). Most focus on habitat for fish but, it can be safely assumed that if habitat is good for fish the invertebrate community will be healthy as well.

Where there are bed structures preventing migration of fish (2), and where flows cannot be sufficiently managed to allow passage, fish passes should be installed. This subject is dealt with in Guidance Sheet 7.

Habitat modification (29) needs to be distinguished from riparian habitat restoration (30). Restoration infers returning to the original status, and can be seen as an additional measure to (speed up) meet WFD environmental objectives. Used alone, without implementation of environmentally acceptable flow release (and monitoring of the impact / effect), the measure is likely to be ineffective in the long term.

Recommendations based on effectiveness for achieving target ecological status
With immediate effect:

- At sites which are identified as significantly at risk the current procedure of using a Q90/95 as a minimum flow, augmented where necessary, should be devised using existing procedures. The method should be reviewed after biological assessments of the systems have been under taken. On small schemes this may not be an economically practical solution.
- There are few scenarios where a compensation flow should not be requested. In a large scheme instances may arise where compensation flows may compromise the attainment of good ecological status in the scheme overall. In very small schemes a compensation flow may compromise the commercial function of the impoundments. In such situations the entire scheme should be reviewed.
- The use of freshets should be encouraged to stimulate fish migration.

- The physical modification of habitat should be considered, at a scale appropriate to the ecological and economic effectiveness.
- Compensations flows are the most basic mitigation measure. They can mitigate against habitat loss, sediment associated problems and help over come barriers to migration. Environmentally Acceptable Flows with temporal (seasonal and flood flow) variation are expected to be more effective

Recommendations related to future developments:

- Rivers downstream of HMWB and AWB identified as at risk should be assessed by ecological survey to determine the current ecological status compared to reference conditions. As suggested in the WFD, reference condition should be defined by comparison with natural water bodies. Data on natural systems exists already.
- An analysis of community compensation data should indicate the reason for deviation
- from reference status, e.g. if the cause is a lack of discharge or a seasonal
- component to the flow regime.
- The suite of potential models should then be reviewed in the light of the findings from the ecological survey and the most cost effective solution identified which achieves the goal of good ecological potential. A model based on hydraulic parameters which have previously been identified as ecologically important using a PHABSIM approach is likely to provide the best ecological return for Volume of water released. It is essential that these minimum flows are augmented by seasonal flows.
- Monitoring post-construction is essential in the short and medium term to provide the data required for demonstrating that flows are environmentally acceptable.

Recommendations for management:

- It is recommended that management include normal and extreme flows (including action to protect habitats if appropriate).
- Implement flexible flow release systems, preferably automated with manned support.

4.5.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 2 can be useful in this step.

A number of example combinations have been provided in Table 4.3 overleaf. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.3: Potential combinations of mitigation measures presented using unique reference in the mitigation measures table in the tables section of this report

Combination	Objective Achieved	Mitigation measures*			
		1	2	3	4
Example C1	*To provide a more natural flow regime*	*21 EAF*	*22 Seasonal Flows*	*20 Flood Flow s*	*29 Physica Habitat Modifica tion*
Example C2		*17*	*18*	*19*	
C3					
C4					

** Case-specific, only an example. See Section 3.10 - Step 7 of this report for more information*

4.5.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Some costs which are potentially relevant are:

– Modelling costs – consultancy and data collation / field sampling.

– Cost to impoundment manager of using impounded water for additional flows. If designed from outset might result in a larger impoundment with a larger dam wall as a result – these are direct costs relating to the use of the water for compensation flows.

– Habitat modification – design and possibly modelling costs prior to construction. May also be some monitoring and maintenance. Cost of materials (may be available locally, even simple movement of existing materials).

– Habitat modification is often expensive. However angling associations will often provide labour if given some financial aid. This is a relatively cheap way of achieving habitat improvement but to gain maximum benefit clear instruction must be given on how the activity is to be carried out.

– Capital and operational cost of variable control structures to allow control over timing and quantity of release.

Related issues to be considered

- Sediment management (Guidance Sheet 9)
- Barriers to migration (Guidance Sheet 7)
- Hydro-peaking flows (Guidance Sheet 1)
- Nature conservation (see Volume 2, Appendix 2)
- flood control (see Section 5.3: Sustainable Flood Management)
- recreational use of the river (Guidance Sheet 10)
- water level fluctuations in the reservoir littoral zone (Guidance Sheet 3)
- Level of flow release points – avoiding stratification and temperature effects (see Guidance Sheet 6)

Before amending flow rates and/or implementing habitat modification/restoration, the needs of existing (protected) natural areas and flood risk areas should be considered.

Input data requirements
Determine target species and collect data on the environmental needs of these species. This includes migration period, location, optimal flow rates (for different life stages), water level, water temperature, and oxygen levels.

Determine water resources available.

Determine existing hydrological regime / management.

Determine hydrological requirements for optimal and minimum dam functioning for the commercial purpose it was constructed.

Determine (hydrological) needs of other users (recreation, flood control, abstraction).

The (maximum) discharge (over time) from the hydropower dam must be compared with release rates from the controlling dam to determine the size of the controlling impoundment and optimal distance between the hydropower dam and controlling impoundment.

Ensure approaches do not increase flood risk upstream or downstream.

Monitoring requirements
Record timing, flow rates, water temperature and oxygen levels after implementation of the $Q_{90/95}$ / EAF, to determine if these match the objective hydrological and physico-chemical objectives. Flow rates, substrate composition, water and oxygen levels should also be monitored at numerous points downstream to determine if these meet the needs of target species.

Identify if species specific monitoring is required.

Key Stake holders:
Groups 1, 3, 5

4.5.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.4) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.4: Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	20, 21, 22, 29						
C2	17,18,19						
C3							

** Case-specific, only an example. See Section 3.12 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.5.7 STEP 10 and STEP11

These steps are generic. Please refer to section 4.3 of this report.

4.6 GUIDANCE SHEET 3: EXTREME WATER LEVEL FLUCTUATION IN THE LITTORAL ZONE

4.6.1 Introduction

This guidance sheet is relevant to all impoundments where sudden release of large quantities of water leads to extreme fluctuations, such as hydropower dams.

Management of the impoundment may result in extreme water level fluctuations within the reservoir. Assessment of the current condition compared to the target ecological status may identify that extreme fluctuations currently result in sufficient loss of habitat for fish, invertebrates or macrophytes to prevent the reservoir from achieving GES or GEP by 2015 under the current operating regime.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this section as succinct as possible, these are discussed once in section 4.3.

4.6.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s):

– Management dam

Pressures:

– Altered water level (fluctuation) in the reservoir

Status and Impact:

– Loss of littoral zone habitat for fish, invertebrates and macrophytes
– Stranding and desiccation of fish, invertebrates and macrophytes on the shoreline
– Flooding of terrestrial plants and trees and high shoreline macrophytes

4.6.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

- Regulation of water levels to meet the demands of biological elements (balance with reservoir functioning requirements) (***32***)
- Install water level gauges to monitor water level and control according to pre-determined 'trigger' criteria (***33***)
- Introduce bunded areas to retain water within defined areas of the reservoir (usually adjacent to the shore) (***34***)
- Excavate pools in the littoral zone to retain water when reservoir levels drop (***35***)
- Introduce fringing reeds and (boating) islands to act as a buffer zone to wave action (***36***)
- Restore shoreline to natural status (***75***) (see Guidance Sheet 4)
- Contingency planning - action plan for unavoidable extreme conditions to protect river habitats (***118***)

Box 3 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 3: Discussion:

In a review of water level fluctuations at 27 lochs in Scotland (Smith et al., 1987) the impact on macrophytes and benthic invertebrates was compared in natural, hydro-power and water supply systems. On the whole the condition of benthic invertebrates in water supply and natural lochs did not differ but in hydro-power lochs macrophytes and invertebrates were almost completely absent from the littoral zone. By comparing weekly and annual fluctuation levels at these lochs, the authors were able to suggest that a weekly fluctuation range below 0.5m and an annual range below 5m were acceptable (***33***). Imposing such limitations on hydro-schemes would be ecologically beneficial but could potentially severely impact commercial dam functioning. A water level management plan for the reservoir (***32***) could be prepared in order to identify site specific targets and appropriate regulation in order to balance the ecological and dam management requirements. (Note: it would be interesting to model the influence of imposing fluctuation limits on the river discharge downstream of the impoundments to determine the impact it would have on downstream biota).

The alternative re-engineering of littoral zones to hold water during periods of fluctuation is more difficult to assess. The introduction of reed fringes (***36***) at Lac de Bourget in France has proved very successful, especially for the local wild fowl population (Friessinet *et al* 2002). Common reed (*Phragmites australis*) is able to withstand dry and flooded conditions to 1m depth once established). In Scotland, pools (***35***) were dug in the littoral zone of Loch Mattock (Smith *et al,* 1987). Other schemes have been considered at Rutland Water where it is difficult to manipulate the littoral zone. These new flooded zones (***34, 35***) are to be constructed adjacent to the impoundment as an alternative. It would be useful to carry out work to assess the improvement in ecological status of the macrophyte, fish and invertebrate communities at these sites in order to fully evaluate the effectiveness of these techniques for achieving GES / GEP.

Contingency planning is required (***118***) as you cannot control the inflow to the reservoir but you can minimise the potential adverse effect of extremely low or high inflows through management.

Recommendations based on effectiveness for achieving target ecological status:

- Consideration should be given to achieving weekly fluctuations limited to <0.5m and annual fluctuations to <5m. It may be necessary in the future to release large flows to mimic seasonal fluctuations downstream of the impoundment. This is an acceptable case where weekly fluctuations may exceed 0.5m. This recommendation may compromise the commercial functioning of impoundments and should not be imposed without full consultation with the impoundment managers.
- The inclusion of physical habitat alterations is achievable for existing impoundments and likely to be effective at minimising the adverse impact (but are unlikely to avoid the impact of extreme fluctuations in water levels completely). Such measures would be best included in the design phase from the outset.

Recommendations for management

- When selecting a (combination of) measures, the wider effects such as impact on recreation and flood management will need to be considered. Site specific data collation and analysis and expert opinion are a must.
- Contingency planning is required (***118***) as you cannot control the inflow to the reservoir but you can minimise the potential adverse effect of extremely low or high inflows through management.

Recommendations based on effectiveness for achieving target ecological status:

- Consideration should be given to achieving weekly fluctuations limited to <0.5m and annual fluctuations to <5m. It may be necessary in the future to release large flows to mimic seasonal fluctuations downstream of the impoundment. This is an acceptable
- case where weekly fluctuations may exceed 0.5m. This recommendation may compromise the commercial functioning of impoundments and should not be imposed without full consultation with the impoundment managers.
- The inclusion of physical habitat alterations is achievable for existing impoundments and likely to be effective at minimising the adverse impact (but are unlikely to avoid the impact of extreme fluctuations in water levels completely). Such measures would be best included in the design phase from the outset.

Recommendations for management

When selecting a (combination of) measures, the wider effects such as impact on recreation and flood management will need to be considered. Site specific data collation and analysis and expert opinion are a must.

4.6.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 3 can be useful in this step.

A number of example combinations have been provided in Table 4.5 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.5: Potential combinations of mitigation measures presented using unique reference in the mitigation measures table in the Tables section of this report.

Combination	Objective Achieved	Mitigation measures*				
		1	2	3	4	5
Example C1	*To minimise the effect of extreme fluctuations in water level*	*32 Regulate water levels to suit biological elements (balance with operational requirements)*	*75*			
Example C2		*34 Create bunded areas*	*35*			
C3						
C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.6.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

- The interaction between littoral zone fluctuations and flows downstream of the impoundment should be considered (also see Guidance Sheet 2)
- Heavy engineering of the littoral zone (see Guidance Sheet 4)
- Flood control (see Section 5.3: Sustainable Flood Management)
- Catchment management (flow input) (see Guidance Sheets 2 and 5)
- Recreational use (see Guidance Sheet 10)

Input data requirements

- current hydrology: inflow, outflow, (seasonal) water levels and fluctuation,

- shoreline morphology, existing development
- target species and (seasonal) hydrological needs, including water depth for reproduction (plant seed set, fish spawning, amphibian egg laying, bird nesting) and depth/ fluctuation for sustaining biota

Monitoring requirements

– Record (seasonal) water levels and fluctuation

Key Stake holders

– Group 1, 3, 5

4.6.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.6) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.6: Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	32, 75						
C2	34, 35						
C3							

** Case-specific, only an example. See Section 3.12 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.6.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.7 GUIDANCE SHEET 4: LITTORAL ZONE DEVELOPMENT, ENGINEERING AND MAINTENANCE IN THE IMPOUNDMENT

4.7.1 Introduction

This guidance sheet is relevant to those impoundments with a heavily engineered shoreline and dam wall.

The impoundment may have been heavily engineered to withstand erosion around the shoreline and at the dam wall. Assessment of the current condition compared to the target ecological status may identify that heavy engineering or intensive maintenance currently prevents the establishment of littoral zone habitats which are important to the ecological functioning of the water body, and hence prevents the reservoir from achieving GES or GEP by 2015 in the current heavily modified condition. It should be recognised that the Heavily Modified nature of the reservoir in the vicinity of the dam wall will result in a less than ideal ecological condition and that the measures proposed aim to improve where possible, rather than aim for natural conditions.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.7.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver:

– Management of the reservoir

Pressures:

– Engineering and intensive maintenance of the reservoir shoreline

Status and Impacts:

– low habitat complexity
– poor species composition
– reduced shore zone surface area
– poor natural functioning of the water body system
– loss of connection with floodplain

4.7.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

- Shoreline restoration
  - Restore or create natural gradient
  - Remove (or cover) piling, rocks, concrete etc. (75)
  - Reconsider changes to adjacent land-use such as lawns, parks, sports fields, pasture and arable land – create natural areas / buffer zones along the shoreline where possible (109, 111);
  - Re-grade the banks (– add material if existing bank material and gradient is required for underlying safety purposes) (77)
  - Reinstate (native) shoreline vegetation
  - Remove non-natural or undesirable vegetation (76);
  - Plant native macrophyte species (8, 15);
  - Install 'soft engineering' solutions (use geotextiles, bio logs, coir rolls, coir mattresses, willow spiling etc. to provide the required erosion protection of the shoreline and to provide a stable media for vegetation growth) (78)
  - Create additional shoreline through installation of vegetated floating islands (81)
- Introduce low-level flooding areas (buffer zones or wetlands) (***79***)
- Develop and implement a maintenance plan which optimises shore zone vegetation development (***80***)

Box 4 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 4: Discussion

The littoral zones of HMWB and AWB are often artificial. Littoral zone development, engineering and maintenance can negatively affect the development of shoreline vegetation and associated fish, birds and macrofauna. Littoral zone development, housing or beaches for example, means a loss of shore zone surface area. In addition, the littoral zones of many impoundments have been artificially designed or (small sections) altered, in many cases to prevent erosion and using artificial material. This engineering means the absence of a natural shoreline gradient and suitable substrate. The use of concrete, for example, provides a simple surface which is not easy to root through and is a poor habitat for macrophytes and invertebrates.

Shoreline restoration is a relevant restoration technique in situations where development or land-use (use of the shoreline for agriculture or recreation), or man-made construction (piling or other man-made shoreline protection) have replaced or limit the development of (natural) shoreline vegetation. It can also be necessary or desirable in cases where increased wave or wind action (as a result of boating or man-made alteration to a lake's hydrology) has damaged or washed away the shoreline. Mechanical damage by waves, waterfowl and mammal grazing, eutrophication and regulation of the hydrological regime can also negatively affect littoral zone development, and should be considered as potential causes before initiating shoreline restoration and/or soft-engineering (see Guidance Sheets 3, 5 and 10).

Shoreline restoration can be as simple as creating conditions in which aquatic and shoreline plants are able to establish, or can be more intensive and involve the removal of unwanted vegetation (***76***) and/or the (re)planting of desired species (***8, 15***). The necessary measures depend on the current situation and to a lesser extent the time in which a well-developed littoral zone must be realized. The percentage scale of the shoreline restoration required to achieve GES / GEP for the whole water body should, however, be considered from the outset.

In situations where non-natural structures such as piling or rocks are present at the shoreline, the first step is to consider whether these structures can be removed (***75***) (question: are they an essential part of the safety / operation / design of the reservoir or can alternative media be used?). In cases where artificial construction is necessary to prevent erosion, materials which are physically complex and allow rooting of macrophytes are a suitable alternative: geotextile mattresses, coir mattresses, coir rolls willow / hazel spiling (vertical fence) etc. (Posford Haskoning, 2003). Work in Germany demonstrates the use of a natural material, gravel, to engineer a beach which is stable. The slope and sorting of the gravel are key to its ability to resist erosion (Friessinet *et al* 2002).

The next step is to create conditions in which the objective (species of) shoreline vegetation can establish. This may require the re-grading of banks. Re-grading can be achieved both through the excavation of the shoreline and through the addition of material onto the existing slope (***77***), where space is available. For example, in shallow water supply reservoirs, where the use of concrete can be extensive, the substrate may become covered in fine sediment. This then provides a semi-natural medium for invertebrates and plants. The actual width and gradient of the shoreline will depend on the amount of space available. The habitat requirements of the target vegetation should be considered when planning the re-grading.

In some instances concrete sides may produce conditions comparable to a natural water body. Lochs and some lakes can have exposed bed rock forming large sections of their littoral zone. This provides a relatively simple habitat with an impoverished fauna and flora which is likely to be similar to that of a concrete shoreline. In such cases it does not make sense to alter the artificial sections of shoreline, as long as the (WFD) target species for the water body are those associated with this type of littoral zone.

Re-vegetation of a shoreline area is desirable if the shoreline design is suitable but native plants have been depleted, bare soils are exposed and/or a fast result is desired. In some cases where the design is suitable, a well designed shoreline maintenance plan (***80***) might be sufficient to realise the ecological WFD targets for the littoral zone. The plan might include the establishment of restricted areas.

The reinstatement of (native) shoreline vegetation has added benefits because it can prevent erosion and serve as a sediment trap for material being carried into a lake via catchment runoff (***109, 111***). In cases where shoreline restoration involves the replacement of agricultural land or sporting fields with natural shoreline, this approach has the added benefit of removing sources of diffuse nutrient and sediment input.

In the long-term, natural shorelines have the advantage of being relatively stable and are (generally) low maintenance.

Restoration of natural shoreline area lost to beaches, housing etc is in many case not a desired option, because of the (recreational) value of the impoundment. The loss of shoreline can be compensated and negative effects on the flora and fauna mitigated by creating low-level flooding areas (***79***) elsewhere in the impoundment

The creation of a semi-natural shoreline, using physically complex material, is best incorporated in the design phase. Not only would there be benefits to the WFD fauna and flora but also for birds and mammals associated with the littoral zone

Recommendations based on effectiveness for achieving the target ecological status

- Consider shoreline restoration and/or soft engineering solutions (where technically possible) when the existing design and/or substrate can be identified as the cause that biological elements do not meet those of good ecological potential.

- A wide range of ‘soft’ engineering solutions are available and are commonly used in river and lake settings where erosion protection is required.

- Ensure the safety function of the impoundment is not compromised

4.7.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 4 can be useful in this step.

A number of example combinations have been provided in Table 4.7 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.7: Potential combinations of mitigation measures presented using unique reference to the mitigation measures table in the Tables section of this report.

Combination	**Objective Achieved**	**Mitigation measures***				
		1	2	3	4	5
Example C1	Create additional suitable habitat for littoral zone vegetation	*79*	*81*			
Example C2		*75*	*77*	*80*		
C3						
C4						

** Case-specific, only an example. See Section 3.10 - Step 7 of this report for more information*

4.7.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Generally speaking, costs will be related to the amount of work required in the restoration and the scale of the restoration. Where the removal of piling and/or rocks is required, excavation costs will apply. The replacement of recreational, pasture and/or arable land will bring with it compensation costs to the owner/s. Replanting will involve the cost of seeds and plants, as well as labour and maintenance costs. The available soft erosion protection measures will have unit costs per m for purchase and installation and most require on-going maintenance. The lifetime varies between measures.

Related issues to be considered

- Extreme fluctuations in water levels (see Guidance Sheet 3)
- Eutrophication (see Guidance Sheet 5)
- Recreation (see Guidance Sheet 10)
- Public and adjacent landowner support

Control or management of extreme fluctuations in water levels in the reservoir may be required before shoreline restoration can be fully realised.

Encouraging macrophyte growth in the littoral zone will help mitigate against eutrophication, especially in small reservoirs. Loss of aquatic macrophytes can be the result of high nutrient levels resulting in softer stems less resistant to wave action (as has occurred with common reed in the Norfolk and Suffolk Broads system).

Wave action from boat wash may need to be addressed before shoreline restoration benefits can be considered or fully realised.

The general public frequently appreciate visual improvements in fringing habitats much more than changes in water quality. In the United States, the public is highly involved with shoreline restoration efforts. Waterfront property owners are asked to protect and enhance the aquatic environment by maintaining or restoring natural vegetation on their property.

Input data requirements

- What is the starting situation?: fetch, current shoreline gradient; potential structures, substrate and/or land-use replacing/obstructing shoreline vegetation development, existing species and habitats;
- What is the objective situation?: what littoral zone species are required to achieve GES / GEP?
- What aesthetic and/or functional goals must be met;
- Define potential area realistically available for shoreline restoration
- Identify other potential causes of poor littoral zone development, e.g. water level fluctuation, recreation, eutrophication.

Monitoring requirements

- Hydrological regime in littoral zone, including wave energy, water level fluctuation
- Species monitoring
- Morphology after mitigation measures

Key Stake holders:
Group 1,3,4,5

4.7.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.8) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.8: Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD- aim in 2015			
C1							
C2							
C3							

** Case-specific, only an example. See Section 3.12- Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise –to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.7.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.8 GUIDANCE SHEET 5: EUTROPHICATION

4.8.1 Introduction

This guidance sheet issue is potentially relevant to all impoundments, but primarily those situated in the lowland catchments.

The impoundment is within a nutrient rich catchment or receives nutrient enrichment from artificial sources. Lowland water supply reservoirs are particularly prone to eutrophication. Hydropower dams tend to be located in the nutrient poor, upland catchments so are less likely to be susceptible to eutrophication, whilst impoundments for flow regulation tend to have relatively high flushing rates.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.8.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s)

- Management of the reservoir
- Management of the catchment

Pressures

- Eutrophication
- Agricultural use of the catchment
- Development in the catchment

Status and Impact

- Reduced water quality
- Nuisance algal blooms
- Fish kills
- Loss of amenity value
- Reduced ecological potential

4.8.3 STEP 6: Identify the potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Catchment based solutions, including:

- Erosion control (***109***)
- Nutrient control (***110***)
- Introduce buffer zones upstream and at the inlet point (***111***)
- Create and manage vegetated deltas for sedimentation at inflow / outflow (***112***)
- Provide phosphorous stripping at source or at the inlet point (***113***)
- (Re)direct inlet flow via (treatment) wetland (***114***)
- Draft and implement a water quality monitoring programme (***116***)

In-reservoir treatments, including

- Provide de-stratification devices (***67***)
- Provide chemical treatment at the inlet point (***68***)
- Increase flushing of the reservoir water (***69***)
- Implement bio-manipulation techniques (***70***)
- Capping of nutrient rich sediments (***71***)
- Removal of nutrient rich sediments (***72***)
- Shoreline habitat restoration (**77**)
- Shoreline habitat maintenance plan (**80**)
- Provide facilities for emptying toilets from boats and providing toilet facilities for visitors (***95***)

Box 5 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 5: Discussion:

Eutrophication is a serious problem in natural systems as well as impoundments. The majority of standing waters in the UK are at risk of failing to meet good status because of nutrient pressures. It is in this national context that the battle against eutrophication will be won or lost and effectively it depends on the political will required to alter land use practices.

Under the WFD there is increasing pressure to deal with eutrophication on a catchment scale.

There is a wide array of measures which can be used to prevent eutrophication both at source and once the problem has reached the impoundment. Eutrophication is a process which is especially hard to reverse so preventative measures are always advised over remedial treatments.

There are a number of guidance documents which describe the various practical measures which can be taken by to prevent nutrients entering freshwater, for example 'The 4 Point Plan. Straightforward guidance for livestock farmers to minimise pollution and benefit your business. (SEERAD, SEPA, SAC, NFUS, SNH, WWF, FWAG and BOC (2004).

Which methods are used depends on whether point source or non-point sources are the main concern. In rural areas non-point (diffuse) sources are thought to be the main cause of nutrient input whilst in urban areas point sources give greatest cause for concern. Both sources are key considerations within the Water Framework Directive.

Recreation is a potential nutrient source. Concerns about organic pollution from boats lead to the provision of toilet emptying facilities by the National Park at Loch Lomond (***95***).

However few standing waters are likely to be so intensively utilised for recreation, especially in Scotland where access to the water is usually controlled by the riparian owner. In general if the shore of an impoundment is visited intensively it is best to provide facilities for the visitors, especially toilets, from which waste can be treated.

If eutrophication has occurred at an impoundment sources must be identified and controlled. Whilst that is the long term aim there are a number of technical solutions which can be imposed with in the impoundments. They main candidates are:

- De-stratification devices
- Chemical treatment
- flushing
- Bio-manipulation

For a completely comprehensive list see, 'Review of Lake Restoration Techniques and Resource Costs' by Posford Haskoning (2003).

De-stratification (***67***) is used primarily to improve water quality but on occasion these devices have been successful in reducing algal blooms (Brierley & Harper, 1999). Reductions happen when phytoplankton are mixed below the depth where light capable of sustaining photosynthesis penetrates for long periods. This method is effective only in relatively deep reservoirs. Among the most successful applications are in water supply reservoirs on the banks of the Thames. The water is injected through directional nozzles which prevents stratification. Other methods include using porous pipes to bubble air up through the water column. De-stratification devices have been used on all sizes of systems, including Rutland Water and designs exist for systems capable of mixing some of Europe's largest lakes (Brierley & Harper, 1999; Lecoffre, 2001). chemical treatment (***68***) reduces the available phosphate. There are a number of compounds used of which aluminium based salts are cheaper than iron based ones. As far as we are aware only ferric sulphate has been used in the UK, probably due to concerns over the toxicity of aluminium. The technique has been used successfully to control phytoplankton blooms but must be used with care if damage to non-target species is to be avoided, e.g. water fleas (Randall et al., 1999). Dosing with ferric sulphate has been used on the largest systems in the UK, e.g. Rutland Water Volume $136.9m^3 \times 10^6$, surface area 1255 hectares

Other solutions include, sediment capping (***71***), flushing (***69***), planting of macrophytes (***77***) and nitrate oxidisation and the physical removal of sediment after drawdown (***72***). Of these sediment removal is probably one of the most expensive (Moss 1996). Flushing of reservoir water (**69**) can be used to remove phytoplankton blooms in reservoirs. This is a short term measure which will not switch the status of the system to a macrophyte dominated condition. In addition, it can have negative impacts on waters downstream.

Bio-manipulation (***70***) encourages macrophyte growth by reducing phytoplankton. This is achieved by removing fish to encourage the growth of invertebrates which feed on epiphytes. Once epiphyte numbers drop macrophytes can dominate once more. The normal techniques involve removing plankton and invertebrate feeding fish and introducing fish eating fish. In some instances hiding places for zooplankton and invertebrates are introduced. Brush wood has been used but it degrades with time and its effectiveness is reduced. There is a clear conflict with angling interests but the overall benefits to the systems are usually thought to outweigh these problems.

A common approach is to use a number of techniques in combination to improve water quality. Solutions to eutrophication have been trialled over a number of years and so, with the possible exception of the bio manipulation approach, all are known to be cost effective. The best way of determining cost effectiveness is to model phytoplankton dynamics within the system. This approach has been used successful during the design phase of impoundments to help identify the susceptibility of a designed system to eutrophication. (Reynolds, 1999) reviews existing models, of which the most applicable in this context is PROTEC (Hilton et al., 1992).

Recommendations based on ecological effectiveness for achieving desired ecological status:

- Where possible eutrophication should be tackled on a catchment scale. This is to address the source of the problem, instead of mitigating the effect.
- Where in-reservoir manipulation is necessary a site specific tailored solution will be required. Bio-manipulation should not be considered for systems with a depth > 3m. There is no size limitation on the application of the other measures although de-stratification is most effective in deep water.
- During the planning phase the system design should be modelled to identify its susceptibility to eutrophication.
- Destratification techniques are preferred to the use of ferric sulphate to avoid damage to non-target species

4.8.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders.

A number of example combinations have been provided in Table 4.9 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.9: Potential combinations of mitigation measures presented using unique reference to the mitigation measures table in the Tables section of this report.

Combination	Objective Achieved	Mitigation measures*				
		1	2	3	4	5
Example C1	Reduced erosion	*109*	*111*			
Example C2		*110*	*72*			
C3	Reduced nutrient input					
C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.8.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

- Sediment management (see Guidance Sheet 9)
- Littoral zone water level management (see Guidance Sheet 4)
- Altered water chemistry (see Guidance Sheet 6)
- Habitat loss downstream
- Recreational use of reservoir (see Guidance Sheet 10)
- Fisheries/ fish stocking (see Guidance Sheet 7)

Input data requirements

- Catchment land use and potential sources of nutrients (point and diffuse)
- Nutrient budget reservoir (including input from fisheries, sediment release and inflow)
- Physico-chemical data (nutrients, temperature, depth, oxygen, etc), current and if available historic
- History of algal blooms

Monitoring requirements

- Physico-chemical data for inflow, outflow and reservoir
- Fisheries data
- Phytoplankton monitoring

Key Stake holders:

Group 1, 3, 5

4.8.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.10) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.10: Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD- aim in 2015			
C1	109,111						
C2	110, 172						
C3							

** Case-specific, only an example. See Section 3.12- Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise –to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.8.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.9 GUIDANCE SHEET 6: ALTERATIONS TO WATER CHEMISTRY, TEMPERATURE AND OXYGEN LEVELS IN THE IMPOUNDMENT AND DOWNSTREAM

4.9.1 Introduction

This guidance sheet is relevant to all impoundments types.

Changes in temperature and water chemistry will be different downstream of any impoundment to the pre-construction status. Significant impacts occur where there is a considerable change in water temperature or when the water has become deoxygenated causing the release of heavy metals and nutrients. This will adversely affect the ecology in the impoundment and in the downstream water body and hence could prevent the achievement of GES or GEP.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.9.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Drivers

- Physical presence of the dam
- Management of the dam
- Management of the reservoir

Pressures

- Release of water with altered temperature to downstream
- Release of water with altered oxygen content to downstream
- Release of water with heavy metal pollution

Status and Impact

- Altered temperature downstream
- Deoxygenation – affecting downstream ecology
- Super saturation – resulting in adverse impact to fish
- Heavy metal pollution due to release of reduced metals from the sediments under anoxic conditions

4.9.3 STEP 6: Identify the potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Temperature

- Maximise availability and draw off of surface stored water (38)
- Draw off water at a number of pre-determined levels through use of a multi-level intake structure (39)
- Provide and fully utilise selective withdrawal structures (40)
- Use hydropower coolant water to manipulate releases and achieve target temperatures (41)

Oxygen levels

- Consider (re)design of outfall to enhance aeration through turbulent flows (42)
- Reduce super saturation of water with oxygen through modifications to the design and operation of turbine structures (43)
- Provide hypolimnetic aeration to improve oxygen levels in the impoundment (e.g. helixors, oxygen injection, air bubblers etc.) (44)
- Provide artificial stratifiers (45)
- Draw off water at a number of pre-determined levels through use of a multi-level intake structure (46)
- Provide and fully utilise selective level withdrawal structures (47)
- Design / retrofit turbines to inject atmospheric oxygen into releases (48)
- Design / retrofit turbines to inject pure oxygen into releases (49)
- Oxygenate water early below the dam (e.g. through creation of riffle sequences) (50)

Water quality – pollutants

- De-stratification devices to prevent reduction of nutrients and metals at the sediment surface (67)
- Bio-manipulation (70)
- Sediment removal (72)

Box 6 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 6: Discussion

Changes in temperature and water chemistry will be different downstream of any impoundment to the pre-construction status. Significant impacts occur where there is a considerable change in water temperature or when the water has become deoxygenated causing the release of heavy metals and the nutrient, phosphate (Bestgen & Williams, 1994) (Armitage 1984).

The release of water at certain draw-off levels especially when stratification occurs during warm weather will only be significant at a local scale and the precise effects will depend on the interaction of a number of local variables, such as thermal characteristics of the original river (governed by diverse factors such as flow conditions of stream and land use of the catchment; thermal characteristics of reservoir and local climatic characteristics (which are significant on both river and reservoir and include factors such as altitude of catchment and its reservoir, exposure of site for direct sunlight and topography to sheltered valley which will have a role in determining temperature conditions.

In water supply reservoirs where the release of nutrients can be an issue, destratification devices (***67***) are used to prevent decreases in water quality (see Guidance Sheet 5). This will also have benefits for water quality downstream of the impoundment too.

If deoxygenated water is re-oxygenated the heavy metals are no longer available and therefore no longer toxic. Diffusion of oxygen to water from air is an extremely slow process so oxygenating water is best affected by vigorous physical mixing. This can be achieved by letting water fall and mix with air at the outfall from the impoundment (***42***). Detailed models exist for calculating the relationship between bed structure and re-aeration (Moog & Jirka, 1999) but in practice it is found that when the bed is rough and flow is turbulent re-aeration occurs rapidly (***50***). Downstream recovery is also determined by the magnitude of heat exchange. Hydraulic conditions in shallow turbulent reaches result in maximum contact between the water and overlying air. In such situations, the water temperature rapidly adjusts to the air temperature and water is usually re-oxygenated within a short distance. In deep, sluggish channels, this recovery is much slower.

Changes in water temperature downstream as result of flow release can be dealt with by taking water from the impoundment at a range of depths and mixing it to achieve a target temperature and oxygenation (***39, 40, 46, 47***). (Petts, 1984) provides examples of the effect of setting abstraction points at different levels in a dam wall. Seasonal target temperatures should be based on temperatures of local river systems of comparable size and the needs of target species. Here again the method used to select reference sites and target species will be important (see Section 2). It would be easier to match temperatures of reference sites on rivers downstream of lakes than ones which were not influenced by a standing water body. It is not easy to suggest an acceptable range of natural temperatures which would be acceptable without further investigation. This is because subtle changes in temperature have been shown to have profound effects on the functioning of benthos below dams, (Raddum & Fjellheim, 1993). However a temperature of greater or less than 5^{o}C ambient in a reference river should be considered extreme. Changes directly but also further downstream should be considered.

The direct heating or cooling of water as a remediation measure is unlikely to be economically viable because of the large Volumes of water involved and the expense of fuel. Where coolant water is available from hydropower plants it could potentially be used to manipulate releases from dams to achieve a target temperature (***41***). Coolant water from electricity plants has been used to culture exotic fish species in the past. Another alternative is to use shallow ponds to heat water to a subtle temperature, e.g. on the River Dee system in Wales water temperature is raised to support coarse fish spawning by constructing shallow pools. These pools do have the draw back of silting up. Water could also be encouraged to cool rapidly by cascading through a channel and mixing with air if ambient air temperatures were sufficiently low. We are not aware of this measure having been used.

Below some impoundments, especially those used in hydropower generation, super saturation with air can occur, causing damage to fish. Modification of the turbine structure to reduce the super saturation of the water with oxygen (***43***) has been investigated in the quest for 'fish friendly' turbines (***66***). This topic is dealt with under entrainment in turbines (see Guidance Sheet 8).

Recommendations based on effectiveness for achieving target ecological status:

- Treatment for heavy metal pollutions in reservoir using destratification devices is most cost effective if the water in the impoundment requires treatment too.
- Treatment for heavy metal downstream by oxygenating the water using channel structure is most cost effective if there is no requirement for the water to be abstracted for use behind the dam.

Temperature of release water can best be regulated by releasing water from different levels within the impoundment

4.9.4 STEP 7: Identify suitable combinations of Mmasures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 6 can be useful in this step.

A number of example combinations have been provided in Table 4.11 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.11. Potential combinations of mitigation measures presented using unique reference in the mitigation measures table in the tables section of this report

Combination	**Objective Achieved**	**Mitigation measures***				
		1	2	3	4	5
Example C1	Reduce effect downstream	*40*	*47*			
Example C2		*50*				
Example C3	Reduce effect in reservoir	*44*	*72*			
Example C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.9.5 STEP 8 Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

– Water quality within reservoir (particularly eutrophication) (see Guidance Sheet 5)
– Fishing and recreation downstream (see Guidance Sheet 10)
– Nature conservation (see Chapter 2)

Changing the release temperature will affect existing biota directly but also further downstream. Before implementation, the value of existing biota in terms of nature conservation and recreation (fishing) must be considered. Also, the potential impact on other recreational users such as boaters and swimmers must be considered. Communication with key stake holders other than environmental and water quality regulators is crucial.

Input data requirements

– Current (seasonal) water quality data for impoundment and downstream (including temperature-depth profile)
– Data on objective water quality, based on reference conditions and/or needs of target species (taking into consideration biota directly and further downstream)
– Presence and requirements of nature conservation areas downstream
– Additional uses of downstream water (fishing, swimming, boating, etc)
– Current operational procedures (e.g. is an existing selective withdrawal structure used to best effect?)

Monitoring requirements

– Temperature, dissolved oxygen, nutrient and heavy metal concentrations at numerous points downstream
– Liaise with stakeholders on effectiveness and identify potential improvements

Key Stake holders

Group 1, 3, 4

4.9.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.12) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.12. Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	40, 47						
C2	50						
C3	44, 72						

** Case-specific, only an example. See Section 3.12 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise –to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.9.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.10 GUIDANCE SHEET 7: MIGRATION BARRIER

4.10.1 Introduction

This guidance sheet is relevant to all impoundments situated online and without adequate provision for fish passage (either via a separate channel or via a fish pass/lift/alternative system).

The physical presence of a dam wall across a river can form a barrier to migration routes for fish passage upstream and downstream and for other species, such as aquatic invertebrates and plant seeds. For GES / GEP to be achieved, provision for fish passage and other target species may need to be provided.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.10.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s)

- Physical presence dam

Pressures

- Loss of continuity
- Loss of fish passage

Status and Impact

- Barrier to migration (upstream and/or downstream)
- Isolation of populations

4.10.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

- Introduce fish pass for movement upstream (e.g. fish ladder, lift and lock system, by-pass, baffled pass etc.) (***2***)
- Introduce fish pass for movement downstream (e.g. overflows for normal conditions, spillways, drop structures, fish friendly turbines etc.) (***9***) (also see Sheet 8)
- Capture / release fish (e.g. trap and truck) (***7***)
- (Re)stocking of native fish species (***6***)
- Restocking and transfer of native animals and plants (***8***)
- Removal (or re-design) of weirs in system (***10***)
- Locate the impoundment off-line (***11***)

Box 7 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 7: Discussion

For historical reasons many major impoundments in the UK have fish passes (2, 9), designed especially to allow the migration of salmonids. More recently the passage of conservation species such as eels has become increasingly important and their requirements are significantly different from the needs of salmonid species.

Many fish passes have been constructed without thoroughly testing their abilities, (Brittain & L'Abée-Lund, 1995). In the UK data is supplied to the Scottish Executive on the numbers of fish migrating through Scottish and Southern Electric impoundments (Fisheries Review 1997-2001). When tested, the ability of fish to navigate past fish passes and ladders can be limited (Gowans et al., 2003). However recent improvements in design may improve matters. In tests salmonids preferred orifice to traditional weir type passes, (Guiny et al., 2003). With orifice type designs water can jet through the orifice making it impossible for salmonids to navigate them. Work at Glasgow University (Alan Irvine, Civil Engineering) is studying the redesign of orifice shape to reduce the jetting effect and make the passes navigable for fish.

Within the Environment Agency there has been a considerable amount of research on barriers to fish movement. The EA National Fish Pass Officer is Greg Armstrong (01437 760081). They have recently produced a manual on fish passes which look at all aspects of fish passes (Armstrong et al., 2004), from legislation, through to choice of pass and for some cases a cost benefit analysis. The type of pass (e.g. Pool and Traverse; Denil; Borland lift etc) selected are invariably site-specific in relation to many factors (local topography, river characteristics, flow, and species) but the requirements for migratory salmonids is paramount with respect to applications for approval.

The American Rivers Organisation reports that fish transported by the lifts (2), locks and the trap and truck (7) methods are often injured or stressed as a result (www.amrivers.org). In addition, the source states little data exists evaluating the success of these techniques in passing viable numbers of given fish species.

The legislation in Scotland governing the requirement for fish passes is different to that in the rest of the UK (The Salmon (Fish Passes And Screens) (Scotland) Regulations 1994). These regulations have been recently undergone amendment. The regulations have supporting documentation on the use of fish passes. Fish passes are invariably site-specific in relation to many factors and thus each one will represent a unique situation when it is considered for approval.

Where it is impossible to use fish passes, the restocking of rivers should be considered (6, 8). Restocking needs to be carried out carefully and should only use animals native to the river section in question and should be reintroduced preferably as embryo rather than as fry. Many fish are reared in captivity and released into the wild. It is well known that hatchery-reared fish have low post-release survival compared with wild fish of similar age. Part of the reason for this high mortality is that hatchery fish show deficits in virtually all aspects of their behaviour (Gozlan 1998).

Financial compensation for fishing rights owners is only deemed an alternative to provision of fish passage for the duration in which a long-term solution is realised (e.g. a fish pass) and would be unlikely to be considered an acceptable mitigation measure under the Water Framework Directive, where the objective is to achieve GES / GEP.

Removal of weirs and obstructions (10) within the river system may enhance the passage of fish generally throughout the system and hence improve the success of fish passes provided at the dam wall. Re-designing existing weirs and obstructions should also be considered. Section 5.2.4 provides information on the considerations related to the decommissioning of dams.

Locating the impoundment off-line (11) from the outset (where topographical / spatial features allow) would avoid the loss of continuity of the natural river channel, although fish passage would still not be guaranteed if the reduction in flow prevented passage over the natural obstructions.

Recommendations based on effectiveness for achieving target ecological status:

The current EA guidelines on fish passes should be followed in England and Wales, with due regard in Scotland to existing legislation and guidance from the Scottish Executive on fish passes. Restocking of fish should only be considered if fish passes can not be used. Only stock native to the system should be used and the fish should be reintroduced as eggs. The need for fish passage and the selection of the appropriate fish pass should be based on the needs of the target fish species to achieve GES / GEP and any Habitats Directive requirements.

4.10.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 7 can be useful in this step.

A number of example combinations have been provided in Table 4.13 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.13: Potential combinations of mitigation measures presented using unique reference in the mitigation measures table in the tables section of this report (Volume 1)

Combination	Objective Achieved	Mitigation measures*				
		1	2	3	4	5
Example C1	Make barrier passable	*2*				
Example C2		*7*				
Example C3		*11*				
Example C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.10.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The choice of fish-passage measure usually comes down to local conditions with the cost considered acceptable if the measure is thought to be effective. The EA manual on fish passages (Armstrong et al., 2004) indicates that costs for baffle fish ways range from £70,000 to £190,000. The EA report also provides a cost –benefit analysis for putting fish passes in place based on the value of a rod caught salmon. Quoted values per rod caught fish were £3000 for River Wye fish and £5647 for welsh rivers. The report is sufficiently comprehensive to cover species of conservation importance such as shad, eels and lamprey.

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

- Fish entrainment in turbines (see Sheet 8);
- Fishing (sport and/or recreation) (see Sheet 10);
- Boating passage (see Sheet 10).

The presence of a fish-passage barrier and also the installation of a fish passage will also impact sport and recreational fishing. If target species are a desired species for fishing, the installation of fish passage will likely be strongly supported by the (recreational) fishermen. If the current barrier is located on a waterway with a recreational value for boating, incorporation of boating passage in the design should be considered.

Input data requirements

- Needs of target (fish)species at different life stages
- Engineering aspects current migration barrier (height, material)
- Location aspects, including gradient, width water channel, flow rate, availability and use surrounding land

Monitoring requirements

- fish tallies above and below passage, including various life stages
- flow rates during migration period

Key Stake holders:
Groups 1,2,3,4 (recreational boating associations) and 5.

4.10.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.14) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.14. Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1							
C2							
C3							

** Case-specific, only an example. See Section 3.12- Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.10.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report
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4.11 GUIDANCE SHEET 8: FISH DAMAGE / KILLS DUE TO ENTRAINMENT

4.11.1 Introduction

This guidance sheet is relevant to impoundments used for hydropower, water supply or flow regulation which incorporate turbines or enclosed water intake mechanisms.

Fish are one of the key biological elements of the WFD. Significant levels of damage or death of fish in the river and impoundment system will adversely affect the success of the fish population and could result in a failure to achieve good ecological status.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach illustrated in section 4.2. The approach is described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this section as succinct as possible, these are discussed once in section 4.3.

4.11.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s)

– Management of the dam

Pressures

– Fish entrainment in intakes

Status and Impact

Critical ecological status, related to the following impacts:

– fish damaged or killed in the turbine or water intake;
– fish kills downstream due to poor water quality (temperature, oxygen – supersaturated and sediment) (see Sheets 6 and 7);
– fish kills in impoundment due to poor water quality and eutrophication (see Sheet 4).

4.11.3 STEP 6. Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

- Divert fish so they do not enter the turbine / water intake (***63***)
- Introduce behavioural barriers (***64***)
- Introduce physical barriers (***65***)
- Use fish friendly turbines (***66***)

Box 8 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 8: Discussion:

Fish damage resulting from passage through turbines has been categorised into mechanical, pressure, shear and cavitation (Odeh and Summers, 2000). Mechanical causes include strike, abrasion and grinding. Pressure changes, shear stress, turbulence and cavitation are all hydraulic characteristics. Once damage mechanisms have been identified, biological design criteria can be determined and incorporated into new and rehabilitated turbines to make them more 'fish friendly' (66). Such turbines are described further below. However, avoidance of entry to the turbine, through diversion channels (63) and barriers address the issue at an earlier stage.

Fish screens or barriers (65, 64) are used to prevent fish entering turbines or water intakes. They could potentially be used equally successfully to exclude fish from areas immediately downstream of outflows where the danger of gas bubble disease is high. Screens come in a variety of forms, including mechanical / physical screens and behavioural screens such as acoustic, bubble curtains, strobe lights and electrical current screens.

Flat and embedded pipe-screens, trash racks, drums and behavioral barriers (strobe lights) have been applied in the US to prevent fish from being swept into turbines (entrainment). Experience in the US indicates that trash racks are only effective if the bar spacing is sufficiently narrow.

In two recent reviews the suitability of these screen and barrier methods was assessed for small scale hydro schemes in the UK (EA in prep). No single measure is thought to be the most suitable; rather it depends on the local conditions. Scottish and Southern Energy Hydro Generation use mechanical screens (65) with internal mesh dimensions of 25mm (horizontal) by 12.5mm (vertical) at many of their intakes to high head turbines to prevent access to smolts. With such mesh materials, the task of cleaning debris off the screens can be very time consuming. Bar screens, which are rakeable, have therefore been investigated by Hydro Generation (Scottish and Southern Energy plc (2002)).

Alternatives to physical screens were also investigated by Hydro Generation. An acoustic screen (64) was trialled at Dunalastair in 1994-1995. At this location, the acoustic barrier stopped the smolts migrating downstream and kept them out of the intake area (as required), but it did not guide them to the fish pass, which is where they needed to be to make an effective exit from the reservoir. There is also a concern relating to power failure, which renders non-physical barriers non-functional (Scottish and Southern Energy plc (2002)).

The US Army Corps of engineers has carried out extensive studies on the damage caused to fish passing through turbines (66), mainly on systems which are large relative to most UK operations. Damage to fish is caused by the fish striking solid objects or damage caused by rapid changes in pressure. The corps carried out a comparison of the risk of fish being struck by turbine blades in Kaplan, Francis and Bulb type turbines (Bell, 1991). The percentage fish surviving passage was highest for a bulb type turbine with a Kaplan turbine faring second and the three Francis type turbines in the comparison faring worst. In all cases over 65% of fish survived and more usually 70-90% of fish survived.

What is clear is that the head and operating efficiency of the turbines have a strong influence on fish survival. Historically the view has been that the highest levels of fish survival occur at maximum turbine operating efficiency. However, in a study on a Kaplan type system, the highest survival was not a peak operating efficiency but at 1% higher, (Normandeau Associates, 2003). In this study the probability of survival was always around 95%. More recent work has found no direct relationship between Kaplan turbine operating efficiency and fish survival, (US Army Corps Engineers, 2004). The same study addressed means of improving Kaplan turbines to increase fish survival. Modifications to the systems are proposed and involve reshaping a number of internal components. A prototype has yet to be built and tested.

In Scotland, Hydro Generation investigated the success of fish passage through a single vertical Kaplan machine at Lairg Power Station in 1998. The results suggested that at 60% load the survival rate of smolt passage through Lairg Kaplan is 91%+. During April and May the normal operating load is higher at between 70 and 90% and, according to previous work at other similar sites in the USA (Heisey et al, 1992), the survival rate would be higher at perhaps 95%. This could not be tested during the trial as the loch level had to be dropped during March / April due to significant flood risk, and hence the operating capacity had to be reduced during April / May. However, Hydro Generation has amended operating procedures at Lairg so that the machine is not run at less than 60% during the smolt migration period (Scottish and Southern Energy plc (2002)).

Further information on operating turbines to be more ‘fish friendly’ is also available in Odeh and Sommers (2000).

There are commercially available designs for fish-friendly turbines such as the Alstrom Vortex turbine. However no data was available to the project on their relative success at allowing fish passage compared to existing designs.

Recommendations based on effectiveness for achieving target ecological status:

It is possible to provide barriers which prevent fish reaching turbines. Data is needed on the relative survival rates of fish passing through fish-friendly turbine systems. Possibly more importantly is the need for information on the relative efficiency in maximising water to generate power when compared to other systems. These data are needed before further recommendations can be made.

4.11.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 8 can be useful in this step.

A number of example combinations have been provided in Table 4.15 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.15. Potential combinations of mitigation measures presented using unique reference to the mitigation measures table in the tables section of this report.

Combination	**Objective Achieved**	**Mitigation measures***				
		1	2	3	4	5
Example C1	Reduce fish entrainment	*66*				
Example C2		*65*				
C3						
C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.11.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

– Fish passage up- and downstream (Migration barrier, Sheet 10)
– Temperature and oxygen levels downstream (Sheet 6)

Input data requirements

- Identify and obtain passage and population data for target fish species and size at different life stages
- Obtain fish damage records (informal data may be available from anglers returns)
- Oxygen levels downstream

Monitoring requirements

- Oxygen levels at numerous points downstream
- Identify if species specific monitoring is required.

Key Stake holders:

Groups 1, 2,4,5,6

4.11.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.16) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.16. Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	65						
C2	66						
C3							

** Case-specific, only an example. See Section 3.12 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.11.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

4.12 GUIDANCE SHEET 9: SEDIMENT MANAGEMENT

4.12.1 Introduction

This guidance sheet issue is relevant to all impoundments which do not provide adequate flushing of sediments through the system during normal operation.

The physical presence of the dam wall prevents the movement of natural river sediment to pass downstream. This can lead to too much sediment upstream of the dam and too little sediment downstream of the dam (with consequential adverse impacts on the geomorphology of the river). If the morphology of the impoundment and river are not suitable for the desired ecological species, then GES will not be achieved.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.12.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s)

- Physical presence of the dam
- Management of the dam
- Management of the reservoir
- Management of the catchment

Pressures

- Continuity
- Altered flow downstream
- Sediment management – too much sediment
- Sediment management – too little sediment
- Eutrophication
- Recreation
- Altered river channel meandering
- Agricultural use / development of the catchment

Status and Impacts

- Too much sediment release to downstream: sediment release through flushing flows results in siltation of downstream habitats and spawning gravels
- Too little sediment release to downstream: net export of bed material below the dam leading to loss of habitat
- Build up of (nutrient rich) sediment in the reservoir

4.12.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Treatment at sediment source

- Catchment management for erosion control (109)
- Provide soft erosion protection measures on the river bank and impoundment shoreline (using geotextiles, coir rolls etc.) (78)
- Introduce fringing vegetation and floating islands / barriers to reduce erosion of the shoreline (36, 93)

Treatment within the impoundment

- Introduce buffer zones upstream and / or by the inlet point to prevent entry of sediment into watercourse / impoundment (54)
- Introduce sedimentation area (vegetated deltas / artificial wetlands) near inflow or outflow of reservoir (55)
- Draw down and remove sediment from behind the dam (dispose) (60)
- Place sediment from behind the dam on the bankside downstream (to contribute to sediment load) (61)
- Place alternative sediment source on bankside downstream of the dam (to contribute to sediment load) (take care to ensure the sediment is sourced from within the catchment and / or has the appropriate physical, chemical and biological attributes) (62)

Flushing through the dam

- Install sluices to allow controlled release of sediments (56)
- Time sediment releases to avoid conflict with fish spawning (57)
- Clean gravel using potable suction devices (58)
- Clean gravel using flushing flows (59)
- Provide a sediment trap downstream of the dam which could be a combined measure for dissipating hydropower energy release (27)

Miscellaneous

- Environmentally Acceptable Flows (21)
- Physical habitat modification downstream (29)

Box 9 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 9: Discussion

Channel degradation usually occurs immediately downstream of the dam. Initially, after the construction period, the hydraulics of the flow (velocity, slope, depth and width) remain unchanged from pre project conditions. However, the reservoir acts as a sink and traps sediment, especially the bed load material. This reduction in sediment delivery to the downstream channel causes energy in the flow to be out of balance with the boundary material for the downstream channel.

Because of the variable energy, the water attempts to re-establish the former balance with sediment from the bed and banks, and this results in a degradation trend. Initially, degradation may persist for a short distance downstream as the equilibrium is soon re-established by removing material from the stream bed.

The lack of sediment supply to downstream reaches prevents the development of in-channel bedform features, such as pool and riffle sequences and bar formations which are ideal for fish and other aquatic populations. Reduced peak flows can result in channel narrowing and stabilisation of bar forms as they become colonised by vegetation due to greater exposure and limited removal of organic matter. Environmentally Acceptable Flows (EAF) (***21***) or physical habitat manipulation (***29***) have both been used to off-set the impacts to the ecological functioning of the system (see Guidance Sheet 2).

To prevent the accumulation of sediment behind the dam wall, sediments are sometimes flushed from the system. This can have negative effects downstream as water quality will drop during the sediment release and fines can accumulate in spawning gravels of fish. Salmon for example are intolerant of fine sediment which can clog gills.

In the impoundment of the Poutes-Monistrol sur l'Allier in France, regular complementary water releases (e.g. an additional 5 m^3 per second) enable minimisation of the storage of solid material and continuous transportation of solid material from the impoundment to the water course (Volume 2, Appendix 1). However, this method is difficult to implement on a water course equipped with a succession of dams, especially if the dams are managed by different owners (e.g. the Dordogne river).

A proactive (rather than reactive) solution is to prevent excessive sediment accumulation in the reservoir and behind the dam wall. This can be achieved by erosion control practices which are similar practices to those also used in the prevention of eutrophication, such as the use of buffer zones (***54, 109***) and altered farming practice in the catchment (***109***). Especially important is to reduce the amount of tilled land in the catchment over the winter period. Techniques for countries where soil conservation is an issue, could be applied, e.g. contour ploughing. Additional opportunities for improved land use to reduce erosion (as well as nutrient input and flood risk) are provided in the report "The integration of Agricultural, Forestry and Biodiversity Conservation Policies with Flood Management in England and Wales.

Erosion protection measures upstream, such as planting of macrophytes (***8***), soft engineering methods in the upstream system and impoundment (***78***) and measures to minimise boat wash (***36, 92, 93***) can also significantly reduce sediment inputs to the system.

Another alternative approach, which would also be beneficial for nutrient management, is to apply sediment-removal measures which cause the sediment to drop out at a location where it can be removed or where it will not cause problems. This would usually be at the entrance to the standing water body / impoundment. One such measure which also benefits nutrient control is the installation of (artificial) reed beds, also referred to as artificial wetlands (***55***). These have been used in numerous eutrophication management plans and artificial reed beds are often used, e.g. Lake Balaton in Hungary.

These systems need to be maintained and repaired so there is an on-going cost associated with them. Alternatively, sedimentation areas can be created near the inflow or outflow of the reservoir. These are easier to dredge, but have less benefit as a nutrient trap. Dredging is also an option in cases where no sediment trap has been installed.

The practice of drawing down an impoundment to remove sediment (***60***) is likely to have severe impacts downstream if a base flow cannot be maintained. In addition, active removal of the sediment is regulated by the Waste Management Licensing Regulations 1994 and may require consent for disposal.

Where sediment must be released from behind the dam wall it is suggested that releases are timed to avoid periods when fish are spawning and when eggs are in reds (***57***).

A sediment trap directly below dam the dam is an option and could be a combined measure for dissipating hydropower energy release ***(27***).

The build up of fines in the water system below the dam may occur simply because of the reduced flow in the system, and not necessarily because sediment has been released from an impoundment. In these situations flushing flows may also be useful to clean fines from gravel. It is now possible to set flushing flows so that habitat features of interest from an ecological point of view are retained or rehabilitated, (Milhous, 1998), (Jowett & Biggs, in prep). Thus, if timed carefully, flushing flows can help restore the seasonality in flow regime. This is discussed further in Guidance Sheet 2.

As an alternative to using flushing flows, downstream gravels can be cleaned manually using a water jetting device inserted into the sediment (***58***) (Scott & Beaumont 1994). This is likely to be relatively costly and only locally effective.

Measures to increase sediment downstream:

In addition to the controlled flushing of sediment through the sluices, active placement of the sediment on the bankside to 'feed' the river downstream (***61, 62***) has been widely used in France (Volume 2, Appendix 1) but is, and will be subject to more stringent consent conditions in the future due to Waste Regulation Licensing in the UK and Europe.

Recommendations based on effectiveness for achieving target ecological status:

- Where possible supply of sediment to the impoundment should be controlled at source.
- Controls for sediment management at source are similar to those used to prevent nutrient runoff from non-point sources. Hence eutrophication and sediment management mitigation measures are likely to have dual benefits. In addition, catchment based sediment and nutrient mitigation measures can also benefit flood control.
- The most cost effective solution for dealing with fine sediment build up downstream is to use flushing flows which if timed correctly may have additional ecological benefits.
- The flushing of sediment through the system ensures a source is available downstream.
- Active movement of sediment from behind the dam wall to the bank downstream is likely to be controlled by the Waste Regulations.

4.12.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders.

A number of example combinations have been provided in Table 4.17 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 4.17. Potential combinations of mitigation measures presented using unique reference to the mitigation measures table in the tables section of this report.

Combination	**Objective Achieved**	**Mitigation measures***				
		1	2	3	4	5
Example C1	Reduce sediment input and improve conditions downstream	*109*	*60*	61		
Example C2		*78*	*27*			
Example C3						
Example C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.12.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to be considered

- Controls for sediment management at source are similar to those use to prevent nutrient runoff from non-point sources. Hence eutrophication and sediment management mitigation measures are likely to have dual benefits;
- Eutrophication (Guidance Sheet 5);
- Flood control
- Altered flow regime (Guidance Sheet 2)
- Waste management
- Fishing interests (Guidance Sheet 7 and 8)
- Recreation (Guidance Sheet 10)
- (Riparian) habitat restoration (Guidance Sheet 4)

Input data requirements

- Sediment budget and eutrophication status for impoundment
- Sediment quality downstream
- Sediment content and composition in release water
- Habitat needs target (fish) species downstream, at different life stages

Monitoring requirements

- Sediment content and composition in release water
- Monitor flow regime and compare with spawning times of target species
- Monitoring channel plant form change and impacts on fisheries/invertebrate habitats

Key Stake holders:
Group 1, 3, 5 (fishing)

4.12.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.18) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.18. Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD- aim in 2015			
C1	109, 60, 61						
C2	78, 27						
C3							

** Case-specific, only an example. See Section 3.12- Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.12.7 STEP 10 and STEP 1

These steps are generic. Please refer to section 4.3 of this report.

4.13 GUIDANCE SHEET 10: RECREATION

4.13.1 Introduction

This guidance sheet issue is relevant impoundments where the reservoir and / or associated river is used for recreational purposes such as boating, white-water rafting / canoeing, angling etc.

Recreational use of the impoundment and / or the river can result in disturbance, the introduction of invasive species or water quality issues which may prevent the achievement of GES / GEP.

This guidance sheet focuses on steps 5 through 9 of the step-by-step approach described in detail in section 3 of this report. Steps 1 through 4, 10 and 11 are generic to all environmental and management issues concerning impoundments. To keep this document as succinct as possible, these are discussed once in section 4.3.

4.13.2 STEP 5: Analyse water system (driving forces, pressures, related status/impact)

The following drivers, pressures, status and impact are associated with this guidance sheet issue:

Driver(s)

- Management of the reservoir
- Management of the catchment
- Physical presence of the dam
- Management of the dam
- Management of the river

Pressures

- Continuity
- Fish stocking
- Recreation, boating, control of hydrocarbon and nutrient input

Status and Impact

- Introduction of invasive fish and macrophytes
- Noise and physical disturbance to wildlife
- Adverse impact on water quality (particularly organic nutrients and Poly-Aromatic Hydrocarbons PAHs)
- Erosion of the shoreline (by boat wash, trampling etc.)
- Development of the shoreline for angling access, mooring, residential (tourist) and commercial use etc.
- Restricted passage for boats and canoes

4.13.3 STEP 6: Identify potential solutions / measures based on effectiveness

Potential solutions for the drivers and pressures associated with this guidance sheet issue include:

Fish / Angling

- Regulate fish stocking (84)
- Provide a tailor-made feeding program for stocked fish to prevent overfeeding (85)

Invasive species

- Complete removal of non-native fish species from riparian and/or impoundment system (86)
- Install screens or barriers to prevent movement of non-native fish species from impoundment to downstream (87)
- Provide signs and liaise with angling associations to prevent the use of live bait for fishing (88)
- Provide signage explaining to people why they must not drop plant material from garden ponds and aquaria into the natural watercourse (89)

Boating / canoeing

- Provide and regulate a spatial zoning system to balance recreation and wildlife needs (designate areas as ‘no entry’ to boats) (90)
- Provide and regulate a temporal zoning system to balance recreation and wildlife needs (control time of year when boating / canoeing access is acceptable) (91)
- Identify approved mooring areas and control use of non-mooring areas (92)
- Install floating barriers to reduce wave erosion on the shoreline (93)
- Install soft erosion protection measures to reduce wave erosion on the river bank and impoundment shoreline (using geotextiles, coir rolls etc) (78)
- Restrict or prevent use of motorised boats (to control / reduce input of PAHs) (94)
- Provide dam release for white-water rafting / canoeing (97)

Boating Passage

- Provide canoe passage for recreational purposes (no. of solutions such as a footpath for portage, dry slide or purpose designed white-water by-pass channel or chute) (12)
- Provide lock structure to allow access for larger boats into navigable waters (13)

Visitor management

- Provide facilities for emptying toilets from boats and provide toilet facilities for visitors (95)
- Control visitor access to the littoral zone (96)

Box 10 contains a discussion of the different measures and makes recommendations for their application based on their effectiveness for achieving target ecological status in particular situations. This information can also be useful when selecting measures in step 7.

Box 10: Discussion

Measures against invasive species

For most standing waters the greatest threat from recreation to the achievement of good ecological status is probably the introduction of pest species by the public.

The release of fish used as live bait during coarse angling can have serious implications for the ecology of a standing water body (Adams & Maitland, 1991; Adams & Maitland, 1998). Reservoirs can act as 'stepping stones' in the spread of nuisance taxa, especially aquatic plants. In recent years *Crassula helmsii* an invasive aquatic plant has spread rapidly through out the UK, following existing nuisance species such as the Canadian pondweed *Elodea Canadensis* (Dawson, 1994; Dawson & Warman, 1987). These species are not known to cause the difficulties noted in hotter countries where invasive macrophytes can cause serious difficulties for dam operation but they often out-compete native flora and their spread should be minimised. Although these plants can spread by natural means the dumping of plant material by man is thought to be a serious fact in hastening their spread.

The importance of invasive species under the WFD is unclear and will depend on the way the biological elements are assessed in each member status. Currently Sweden uses a ratio of native to non-native fish species as an ecological quality ratio, (Swedish EPA, 2000). The Swedish system, in general, has been suggested as a good system for the UK to follow in its implementation of the Directive (Murphy *et al* 2002).

To control the spread of invasive species, signs at access points to standing water bodies can be used asking people not to use live bait (***88***) and not to dump material from their garden ponds and aquaria (***89***). Liaising with local and national angling associations is essential. The need to use signs will depend on the access of the public to the site and whether or not a reservoir is used for coarse fishing. Although coarse fishing is less common in Scotland than elsewhere, pike are fished for and live bait is used. Screens can be installed at the outlet point as a measure to prevent the spread of fish to downstream waters (***87***).

Disturbance

The physical presence of boaters and swimmers has a disturbing effect on plants and animals, especially in the shallower areas. As a result, the vegetation will be less well developed, potentially leading to increased turbidity due to algal growth and suspended solids. Effects can be mitigated by establishing 'no entry' zones (***90, 96***) and limiting boat docking to specific areas (***92***).

Spatial zoning of reservoirs (***90***) is commonly used in the UK to provide quiet, undisturbed areas for wildlife, whilst allowing recreational boating (e.g. Loch Lomond, Grafham Water, Rutland Water) in defined areas. Temporal zoning (***91***) of recreational use of the river is commonly used for balancing white-water rafting / canoeing interests with suitable flows and angling requirements.

Wave impact on the shore can be reduced by introducing (floating) barriers (***93***) within impoundments and soft erosion protection measures within the river (***78***).

The physical presence of beaches, docks and other shoreline development for recreational purposes also negatively impact the flora and fauna in the littoral zone. This "littoral zone engineering"is discussed in Guidance Sheet 4.

Water Quality

Pollution from recreation is serious only in extreme cases. There have been concerns that pollution for boats may reduce water quality. Work in Scotland suggested that boat exhausts could produce toxic levels of Poly-Aromatic Hydrocarbons (PAH) (Bannon *et al* 2001). However it is not yet clear how long these chemicals remain in the water and how significant their impact actually is. At some lakes only wind powered recreational craft are allowed as a precautionary measure, e.g. Lake Constance, Germany. On water supply reservoirs it is common practice to severely restrict the used of engine powered craft (***94***). At Lake Tahoe, California, research has indicated that exhaust from boats and especially wave runners has had severe impact on the transparency of the water.

Organic waste from boats and recreational bungalows can also be a potential nutrient source, negatively affecting the water quality. This issue is discussed in Guidance Sheet 5, 'Eutrophication'.

Concerns about organic pollution from boats lead to the provision of toilet emptying facilities by the National Park at Loch Lomond (***95***). However few standing waters are likely to be so intensively utilised for recreation, especially in Scotland where access to the water is usually controlled by the riparian owner.

In general if the shore of an impoundment is visited intensively it is best to provide facilities for the visitors, especially toilets, from which waste can be treated (***95***).

The provision of access routes around dams to allow the passage of canoes etc. to continue downstream (***12***). This can be provided as a simple footpath or set of steps, as a dry slide for boats to be carefully passed down or a separate white-water channel or chute with opportunities for recreational gain (e.g. Tyne, Holme Pierre Pont on the Trent). Provision of a lock structure is required for passage of larger vessels on navigable waters (***13***).

Recommendations based on effectiveness for achieving target ecological status:

- Preventing the spread of invasive species will contribute to GEP
- Further research on the impact of PAH from boat traffic needs to be evaluated.
- Limitations to recreation should be considered but balanced against the positive benefits for people and the environment of the activity

4.13.4 STEP 7: Identify suitable combinations of measures

In step 6, a number of potential mitigation measures for this particular guidance sheet issue are named and discussed. The next step is to identify potential combinations of measures with which the desired (target) ecological status can be achieved. This requires interaction between the technical team and the impoundment stakeholders. The information and recommendations in box 10 can be useful in this step.

A number of example combinations have been provided in Table 4.19 below. Section 3.10 – Step 7 of this report provides additional information on selecting combinations of measures. It cannot be emphasised enough that suitable (combination) of measures and their effectiveness depend on the current hydromorphological, physico-chemical and biological status of a particular water body, the target status as well as other related issues (see step 8). Suitable combinations are therefore case-specific, and thus cannot be prescribed in this guidance sheet.

Table 3.19. Potential combinations of mitigation measures presented using unique reference to the mitigation measures table in the tables section of this report.

Combination	Objective Achieved	Mitigation measures				
		1	2	3	4	5
Example C1	Reduce disturbance	*96*	*92*	93		
Example C2	Reduce imported exotics	*84*	*86*	87		
Example C3						
Example C4						

** Case-specific, only an example. See Section 3.10- Step 7 of this report for more information*

4.13.5 STEP 8: Calculation of financial and socio-economic costs

For each of the selected combination of measures, the financial costs and other possible issues including the socio-economic effects need to be identified. Financial costs and other issues related to this guidance sheet issue are presented and discussed below.

Financial costs

The costing spreadsheet (tables section of this report) provides an overview of some of the financial costs, but the most accurate method for calculating financial costs of mitigation measures is to liaise with the operator and manager of the impoundment(s) being considered as well as other impoundment operators who have installed similar measures. For this reason, no costs are presented here.

Related issues to consider

– Eutrophication (Guidance Sheet 5)
– Seasonal flows (freshet release for recreational use) (Guidance Sheet 2)
– Littoral zone engineering (Guidance Sheet 4)

In order to gain support from the public, representatives of the various recreational organizations should be involved in the development of a management plan. The benefits for fishing, conservationists, etc should be clearly communicated.

Input data requirements

– Boating intensity, to quantify pollution and extent of disturbance
– Vegetation coverage within the impoundment, in relation to water depth
– Fish and flora species data for impoundment and downstream, to determine if exotics are present and negatively impacting the development of target species
– General information about current use and hydro-morphological status of impoundment

Monitoring requirements

– Fish and flora species data
– Monitoring of “no entry” areas, including human disturbance and ecological development within the area

Key Stake holders:
Group 1, 3, 5

4.13.6 STEP 9: Rank combinations according to cost-effectiveness

A table such as presented below (Table 4.20) can be used to rank the combinations of measures according to cost-effectiveness.

Table 4.20. Tool for selecting the most appropriate combination of measures

Selecting the most appropriate combination of measures							
Nr.	Combination of measures	Chance to reach WFD-aim*			Net Present Value*	Other socio-economic effects*	Ranking of measures based on cost-effectiveness*
		Effect	Period	Chance to reach WFD-aim in 2015			
C1	96, 92, 93						
C2	84, 86, 87						
C3							

** Case-specific, only an example. See Section 3.10 - Step 9 of this report for more information*

The outcome of this step is a ranking of each of the options to determine the most appropriate combination of measures. As mentioned in step 7 it is recommended that stakeholders be involved in the exercise to make the judgemental evaluations; identify related issues and partake in the ensuing decision; hereby increasing the chances of the decision being acceptable.

4.13.7 STEP 10 and STEP 11

These steps are generic. Please refer to section 4.3 of this report.

5 INTRODUCTION

Although the original project aimed to cover all impoundments, following discussions with the steering group the project was reduced in scope and this document provides a tool for identification and assessment of measures related to hydropower, water supply and flow regulation in freshwaters. It is recommended that a similar approach be followed in developing guidance for the remaining types of impoundments relating to: nature conservation; irrigation; waterside development; flood prevention and/or storage; navigation and marinas; and recreation.

This section discusses some of the other issues which are relevant to impoundments and considers wider issues such as issues relating to the construction of new dams, the decommissioning of existing dams and also provides a brief overview of information relating to impacts of dams on sustainable flood management practices and impoundments associated with transitional and coastal waters.

5.1 Preventative measures to be taken: consideration of design, construction and decommissioning

The majority of the mitigation measures and management strategies identified in the guidance sheets and spreadsheet in this document relate to the operational phase – and hence are aimed at ensuring existing impoundments meet GES / GEP under the WFD within the required timescale. Incorporation of these measures during the design phase of new impoundments has significant cost, time and effectiveness benefits.

5.1.1 Design phase

Outlined below are the mitigation measures most relevant to the design phase of an impoundment. Before anything else, the proposal to have the impoundment should be compared with other alternatives (for example, there may be different alternatives for water supply and the option to construct an impoundment may not be the best environmental or socio-economic option).

Maximising the ecological benefit of a new reservoir
Before constructing a new impoundment it is important to consider the conservation status of the habitat being created as well as that being destroyed. The assessment of the environmental impacts of the construction and operation of impoundments is also important and is usually a legal requirement under the provisions of the Environmental Impact Assessment Directive.

The location of the impoundment is a significant factor due to the potential effects dams may have on drainage, possibly over a wide area. The provision of buffer zones between surrounding farmland and impoundments can be used to limit silt and nutrient run-off and thereby prevent deteriorations in water quality both within the impoundment and downstream.

Where possible, new dams should be situated near to existing wetlands or semi-natural habitats as this will extend rather than fragment habitats, potentially through raised groundwater levels in suitable substrates. Potential adverse impacts on such habitats, should, however be thoroughly investigated and avoided through location or mitigation.

The provision of a variety of habitats should also be considered. Varying the shoreline of the water body is a good way of increasing habitat variability through the provision of bays. Shallow marginal areas, the building of shallow ledges and a planting programme will aid plant establishment and growth. Only naturally occurring species should be used in the planting programme.

The slope of the shoreline should be predominantly shallow to allow vegetation to accumulate and allow access by wildlife. The inclusion of some vertical areas will increase habitat variability as will varying the depth of the water body itself.

Artificial nesting sites and islands should be considered.

Where abstraction is likely to lead to sudden variations in water level, the provision of shallows and permanent pools will limit the impact.

Eutrophication
Where eutrophication is thought to be a potential problem, ecological models can determine the actual risk and help suggest mitigation measures for inclusion at the design phase although it is always better to deal with the causes of eutrophication at source and consideration of catchment management programmes to reduce eutrophication should be considered.

There are a number of preventative measures that can be taken at the design phase. These include increasing the depth of the reservoir, planning the orientation of the reservoir, controlling sediment inflow, considering the optimal residence time within the impoundment and installing de-stratification devices. These measures will help to limit the accumulation of nutrients, especially phosphates though which measures are used depends on whether the inputs are point source or diffuse. De-stratification devices may also be used to prevent heavy metal pollution.

Hydropower releases/water level fluctuation
Careful design of the way water is released from the dam is the most appropriate method for reducing the potential impact of hydro peak flows. Provision for the additional flow / storage capacity needs to be incorporated from the outset and may result in a more substantial dam and reservoir structure as a result. However, lessening the damaging impact of sudden water releases by building controlling impoundments downstream may also be used. The digging of pools in the littoral zone is another alternative.

Fish entrainment in turbines
There are a variety of types of screen that can be incorporated into the design of the intake to prevent fish from entering water intakes or turbines and these have been detailed in the mitigation measure spreadsheet.

Sediment management
The design-phase solutions to problems with sediment are similar to those for limiting eutrophication and are concentrated on dealing with the problem at source and at a catchment level. The orientation of the dam, buffer zones and surrounding land use are all important considerations. The planting of reed beds may help with reduce sediment input.

Littoral zone engineering

The most obvious problem relating to the littoral zone is the use of concrete to prevent erosion. Overlaying layers of gravel may alleviate the problem to some extent. The best solution is a semi-natural shore line incorporating more physically complex materials such as gravel which allow macrophytes to root. This is only worthwhile over large areas.

5.1.2 Construction phase

An Environmental Impact Assessment undertaken during the outline design stage of the impoundment will identify the key potential impacts and mitigation measures required during the construction phase of a scheme. In general, the following should be considered:

– water resources – water diversions, temporary dried stretches, time to fill the reservoir, water availability for filling, reduced availability to water resource users downstream during filling.
– water quality – sediment and contaminants released downstream due to tracking of construction machinery etc. in the river. Impact on ecology, water resource users, visual and amenity interests. – mitigation: adherence to Pollution Prevention Guidance for in-works in or near watercourses and general construction measures etc oil storage
– ecology – prevention of fish passage during construction, water quality issues and sedimentation / fines blanketing river bed and macrophytes, direct loss of species / habitats during to footprint of dam and haul / access routes.

5.1.3 Operational phase

This is the main focus of the Guidance Sheets and Mitigation Measures spreadsheet present the key mitigation measures that can be undertaken during the operational phase of the impoundment.

5.1.4 Decommissioning phase

Case studies on the decommissioning of dams in France and the USA are provided in Volume 2, Appendix 1, along with a useful checklist on the re-licensing of small hydropower dams in the USA

The following outlines the key considerations of dam decommissioning applicable to the UK.

Feasibility assessment of decommissioning:
The future of an impoundment falls within three broad categories: maintain the current structure, a change of use or the removal of the structure.

The driving forces for consideration of dam removal are:

1) The cost of maintenance and repair when the benefits of maintaining a dam are diminished;
2) Public safety and liability concerns;
3) alternative sources of hydropower, irrigation and public water supply or other dam functions; and
4) Potential fisheries, water quality and recreational use improvements that can be realised with dam removal.

All of the above should be investigated, with significant opportunity for full Stakeholder Participation to identify and prioritise potential issues and concerns.

1) Cost and 2) Public safety / liability concerns

The question is "Who pays for the decommissioning of dams?".

Under the Reservoirs Act 1975 (and its predecessor 1930's Act), UK reservoirs exceeding 25000m^3 are required to be inspected at least once every ten years by an Inspecting Engineer (approved 'Panel Engineer'). The Inspecting Engineer may require measures to be carried out in the interest of **safety** and the dam owner is legally obliged to undertake works as soon as is practicable (Bridle and Sims, 1999). Since the introduction of the 1930s Act, there has been no fatality resulting from dam failure in the UK.

In the US dam removal costs in many cases are significantly less than estimated expenditures for long-term safety and environmental compliance, repair, and maintenance (International Rivers Network, 2004).

Ideally, the costs of decommissioning for environmental gain should also be borne by the dam owner. However, in the UK the vast number of historical dams (1,947 dams constructed before 1950 i.e. 75% of total of UK dams) and the lack of incentive for the current owner to spend money on decommissioning, results in funding being sourced from government or non-governmental organisations seeking to restore the river for other purposes.

A good example of best practice for removal of existing dams is Pacificorp, a major regional power company in the USA, who promised to finance the removal of the Condit Dam on the White Salmon River in Washington through a decommissioning fund generated by future hydropower revenues.

Dam-owner acceptance of financial accountability for the decommissioning costs of *future dams* should, therefore, be incorporated into time-limited licensing agreements to avoid doubt in the future (as is achieved in the nuclear industry).

3) Alternative source of dam function

A key aspect of dam removal planning is early identification of alternative sources of hydropower, irrigation and public water supply, or other dam functions. Developing a comprehensive management plan that accounts for displaced dam functions minimises the negative impacts of removal. Dam removal often entails trade-offs between competing river functions. However mitigation measures, such as improving efficiency of irrigation systems can result in only negligible effects on water supplies. Where changes or impacts are unavoidable, society may accept them as the price of long-term river restoration.

4) Potential environmental benefits (and dis-benefits)

In the context of the Water Framework Directive (and other legislation such as the Habitats Directive) the benefits of decommissioning the dam should be investigated in terms of the contribution towards achieving Good Ecological Status (and Good Water Status which includes hydromorphology and physico-chemical status). In many cases, this will include improving migratory routes for fish, reinstating natural (including seasonal) river flows and hence benefiting all biological elements. Wider environmental benefits include recreational and navigational benefits and increased water resources.

In terms of dis-benefits, the decommissioning of the dam may result *inter alia* in the loss of a recreational resource, changes to the flood regime, loss of wetland habitats associated with the higher water levels upstream and changes to water resource availability.

5.1.5 Deconstruction phase

During the analysis of data (step six), an assessment should be made of the consequences of emptying the water body, the precautions to be taken due to the significantly silting up of the impoundments, the presence of fish and the impact to ecology, the impact to current abstraction and discharge agreements, the stabilisation of water levels and the localised impact to the economy.

For example: The Impact of Sediment Release:

The removal of sediment, as a precaution to prevent or reduce the impact of sudden release of (potentially contaminated) sediments, is likely to represent the most costly and technically intensive aspect of decommissioning large dams.

Factors influencing sediment removal techniques include:

- the quantity of sediment,
- the quality of sediment (presence of priority substances etc.)
- reservoir characteristics,
- project age, and
- the effectiveness of periodical flushes, if at all feasible, to pass trapped sediment downstream.

Sediment removal must be conducted carefully, as excessive release can damage sensitive downstream habitat. A potential effect of sediment flushing is release of accumulated contaminants into fisheries or water supplies. Hazardous waste in sediment poses significant health risks, degrades water quality, and ultimately requires extensive cleanup efforts. Thus, thorough sediment analysis and prior assessment of the foreseeable effects of releasing sediment must be included in decommissioning studies.

5.1.6 Post-decommissioningpPhase

Experience has shown that fisheries and hospitable habitat conditions return quickly after a dam is removed. However dam removal alone may be insufficient to fully restore river systems and may need to be accompanied by additional measures, such as protection of native fisheries, pollution abatement, restoration of riparian habitat, and stricter watershed management policies to increase the rate and extent of restoration.

5.2 Impoundments and sustainable flood management

5.2.1 Introduction

The Water Framework Directive seeks to mitigate the effect of floods. The topic of impoundments and sustainable flood management is discussed in this section under two sub-headings:

- the impact of impoundments and their management on sustainable flood management and;
- the use of impoundments for sustainable flood management.

This brief review provides an introduction to the topic, which it is hoped will be the subject of a Guidance Document in it-self in the near future.

5.2.2 The impact of impoundments and their management on sustainable flood management

Impoundments can attenuate flooding downstream up to the capacity limit of the reservoir. This is achieved through reducing the peak of the flood hydrograph by the filling of the reservoir and controlled release of the flood water downstream.

Once the capacity of the reservoir is reached, however, the flood flows continue downstream without attenuation.

The flood attenuation effect of the impoundment is significantly reduced if there is second (or more) consecutive storm event(s) before the impoundment is able to discharge the flood waters from the first event. The full impact of the latter storm events is then experienced downstream of the impoundment and upstream flooding impacts can also be aggravated due to the backing up of flood waters behind the dam.

Catastrophic failure of the dam wall would lead to the sudden release of water / flood water downstream, leading to a significant risk to life as well as property and infrastructure. Safety issues are therefore paramount in the UK, where the Reservoirs Act 1979 requires strict design, monitoring, maintenance and control procedures for impoundments. However, it should be noted that the Reservoir Act requirements are scaled according to the physical parameters of the dam in respect of large and raised dams with a storage capacity greater than 25000m^3 (ICE, 1996). The essential requirement is that the dams must overtop safely and not breach.
Flooding upstream of the impoundment requires detailed consideration during the design and operation of the impoundment. There are a number of approaches (which are often used in combination) to mitigate this potential effect:

- Design the capacity of the impoundment to receive the larger flood events;
- Manage water levels in the impoundment so that larger flood events can be accommodated when required (requires sensitive operational practices and predictive or telemetry readings for water levels upstream);
- Set the overflow so that flooding upstream cannot occur; and
- Provide flood walls / embankments for property and infrastructure upstream to prevent flooding.

As an example, Hydro Generation has a control room at Clunie Power Station that has the ability to monitor and record reservoir and river levels at all important locations. There is a reciprocal arrangement by which SEPA has remote access to Hydro's gauging information and Hydro has access to the SEPA's data. This is important for environmental reasons (i.e. management of compensation flows / freshets etc.) but is also crucial for **flood warnings** and control (Scottish and Southern Energy plc., 2002).

5.2.3 The use of impoundments for sustainable flood management

The concept of flood storage upstream of the property or infrastructure to be protected is considered to be an important option within the identification of Sustainable Flood Management practices. There are a number of potential benefits of a flood storage impoundment (depending on local conditions):

- Reduces flooding downstream;
- Floods an area of less economic / social or habitat value upstream and hence protects valuable land and property sensitive to flooding downstream;
- Redistributes floods so reducing the impact of them overall;
- Encourages flood plain restoration and managed realignment within the system (upstream and downstream);
- Allows recharge of groundwater;
- Provides a useful resource for other uses – such as recreation, tourism etc.
- Provides opportunities for the development and management of valuable wetland / habitat creation
- Provides opportunities for species suited to wetland and aquatic habitats; and
- Reduces or avoids the need for flood walls and embankments downstream.

There are a number of different types of impoundment used for flood management including:

- Off-line storage (without impoundment of the main water course);
- Impoundment of the river to direct the water into an off-line storage area;
- On-line storage impoundment with control on all flows; and
- On-line storage impoundment with control on flood flows only.

In terms of achieving the requirements of the Water Framework Directive, where impoundment of the river is required this should be designed to:

- Avoid interrupting normal and minor flood flows;
- Maintain river continuity as much as possible (including upstream and downstream migratory routes);
- Allow sufficient flow velocities to flush sediments downstream (10m3/s should be sufficient) and hence avoid accumulation upstream and avoid sediment 'starvation' downstream;
- Allow sufficient flow velocities to allow natural geomorphological processes downstream (e.g. meanders, riffle / pool sequences etc.); and
- Incorporate other site specific considerations as appropriate.

The design of the mechanism for controlling and releasing flood waters is also a significant consideration. Mechanisms include:

- Fixed orifice – a throttle system which is designed to release only as much flood water as the channel downstream can carry without flooding. An overflow mechanism is required with this system for flood events (or combinations of events) greater than the design capacity of the impoundment;
- Variable orifice – a controllable system using sluices or penstocks. The control mechanism can be manual or automated and is triggered according to upstream water levels. The sensitivity of the control mechanism determines the level of hydropeaking flows downstream, which can be managed to provide a positive variability in flows rather than seen as a negative effect of less sensitive management; and
- Pumped system – allows variable control but generally used on systems requiring discharge against a head of water. For example, raising water from low lying land to a highland carrier system (e.g. on the Cambridgeshire Fens) or pumping water into a tide-locked system.

The operation of impoundments for flood management will significantly affect the potential for the achievement of the WFD objectives. The timing of flood storage and the release of flood waters is particularly important in this regard.

5.3 Impoundments on transitional and coastal waters

The following section provides a brief review of the considerations relating to impoundments on transitional and coastal waters.

Examples of impoundments associated with transitional and coastal waters include barrages for:

- Visual amenity – raising water levels for water-side development in urban areas, for example the Cardiff Bay Barrage;
- Freshwater resources – raising water levels and preventing ingress of salt water to enable abstraction of fresh water for industry and potable supply;
- Recreational amenity – to create a body of water for recreational boating etc; and
- Navigation – to create a permanent depth of water suitable for navigation (commercial and recreational), for example a port or marina development.

Key considerations include:

- Creation of a physical barrier between salt and freshwater systems, with associated impacts such as:
- removal of important estuarine habitats and impacts upon associated estuarine species and coastal productivity; and
- the blocking of access to and from the sea / freshwater for migratory fish species (both anadromous and catadromous).

- The loss of intertidal areas on the landward side of any barrier as tidal effects cease can have natural heritage impacts. These can be particularly significant for bird species using intertidal areas as feeding areas;
- Alteration of the hydrodynamic regime of both the fresh and salt water component of transitional waters. On the landward side in particular there is potential for stagnation and eutrophication; and
- Impacts on coastal processes due to the loss of sediment contribution from river / estuarine systems, with implications for coastal erosion / sedimentation.

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TABLES

Driving force	Pressure	Guidance Sheet No.	Mit. Tech.No.	Mitigation technique	Impact on WFD Indicator Species			
					Phytoplankton	Macrophytes and phytobenthos	benthic invertebrates	fish fauna
Physical presence of the dam	***Continuity***	***Sheet 9***	***1***	Filtration to remove particulate organic matter in reservoir	+	+	?	+
		Sheet 7	***2***	Introduce fish pass for movement upstream (number of alternatives including fish ladder, lift and lock system, trap and truck, by-pass, baffled pass etc.)	~	~	~	++
		Sheet 10	***3***	Flushing of Sediment (constant)	-/+	-/+	-/+	-/+
		Sheet 9	***4***	Controlled release of sediment (timed to avoid impacts on ecology downstream)	?	++	++	++
		Sheet 1	***5***	Riparian habitat restoration	?	+	++	++
		Sheets 1 and 7	***6***	(Re)stocking of (native) fish species	?	?	?	+
		Sheets 1 and 10	***7***	Capture/release fish as required	?	?	?	+
		Sheets 4	***8***	(Re)planting of native macrophyte species	?	++	+	+
		Sheet 10	***9***	introduce fish pass for movement downstream (spillways, drop-structures)	~	~	~	+
		Sheet 7	***10***	Removal of weirs and other obstacles	~	~	~	-/+
			11	locate the impoundment off-line	?	?	?	?
		Sheet 9	***12***	canoe passage for recreational purposes (no. of solutions such as footpath for portage, dry slide or purpose designed white water channel / shute)	~	~	~	~
			13	provide lock structure to provide access for larger boats into navigable waters	-/+	-/+	-/+	-/+
	Altered habitat	***Sheet 3***	***14***	reduce angle of lake sides	-/+	++	+	+
		Sheet 4	***15***	plant marginal species		++	+	+
Management of the dam	***Altered flow downstream***	***Sheet 2***	***16***	Raise and lower flow rates gradually (to avoid hydropeaking type flows changes)		++	++	++
			17	set minimum flow rates (*minimum compensation flows* also called *base flows*)		+	+	+
			18	set maximum flow rates	?	?	?	?
			19	Provide *freshets* to mimick natural floods (and encourage upstream migration of fish) (also used on recreational rivers for white water rafting)	++	++	++	++
			20	Provide *flushing flows* to replicate major flood events and flush fine sediments out of spawning gravels	~	+	+	++
Management of the dam	***Change to river habitat***	***Sheet 1***	***21***	provide *environmentally acceptable flows* (imitate natural flow regime)	~	++	++	++
			22	Provide *seasonally variable flows* combined with environmentally acceptable flows	~	++	++	++
			23	Consider *night time releases*	~	~	?	+
			24	controlled spill to meet water demands of biological elements (primarily fish) downstream	~	+	+	+
			25	real-time operation to meet water demands of biological elements (primarily fish) downstream	?	?	?	?
			26	Introduce (artificial) meander directly downstream of dam to dissipate energy	~	+	+	+
			27	Introduce buffer zone of deeper water directly downstream of dam to dissipate energy	~	+	+	+
			28	Create multi-stage channels	~	+	+	+
			29	Physical habitat modification to improve depth and velocity of existing flows	~	+	+	+
			30	riparian habitat restoration (meanders, ripples, substrate etc)	~	~	++	+
			31	bank protection to prevent erosion	~	+	+	+
	Altered water level (fluctuation) in reservoir	***Sheet 3***	***32***	Draft and implement water level regulation which meets demands of biological elements, fish spawning in particular (set (seasonal) minimum and maximum water levels and maximum fluctuation) (balance with reservoir functioning requirements)	+	+	+	++
			33	Install water level gauges to monitor water level and control according to pre-determined 'trigger' criteria	+	+	+	+
			34	introduce bunded areas to retain water within defined areas of the reservoir (usually adjacent to the shore)	+	++	++	++
			35	Excavate pools in the littoral zone to retain water when reservoir water levels drop	+	++	++	++
			36	Introduction of fringing reeds and (boating) islands to act as buffer zone	+	++	++	+
	Altered residence time within reservoir	***Sheet 3***	***37***	Increase flushing to reduce the residence time	++/-	+/-	+/-	+/-

Driving force	Pressure	Sheet No.	Tech.No.	Mitigation technique	Impact on WFD Indicator Species			
					Phytoplankton	Macrophytes and phytobenthos	benthic invertebrates	fish fauna
Management of the dam	***Release of water with altered temperature to downstream***	***Sheet 6***	***38***	Utilise surface storage	?	?	?	?
			39	Draw off water at a number of pre-determined levels through use of a multilevel intake structure	~	++	++	++
			40	Provide and fully utilise selective level withdrawal structures	~	++	++	++
			41	Use of hydropower coolant water to manipulate releases and achieve target temperature (direct heating or cooling of water unlikely to be viable)	~	++	++	++
	Release of water with altered oxygen content to downstream	***Sheet 6***	***42***	Consider (re)design of outfall to enhance aeration through turbulent flows	+	++	++	++
			43	Reduce supersaturation of water with oxygen through modification of the design and operation of turbine structures.	?	?	?	?
			44	Hypolimnetic aeration to improve oxygen levels in the impoundment (eg. Helixors, oxgen injection, air bubblers etc.)	**++**	**+**	**+**	**+**
			45	Provide artificial destratifiers to improve oxygen levels within impoundment	**++**	**+**	**+**	**+**
			46	Draw off water at a number of pre-determined levels through use of a multilevel intake structure	~	++	++	++
			47	Provide and fully utilise selective level withdrawal structures	~	++	++	++
			48	Design / retrofit turbines to inject atmospheric air into releases	?	?	?	?
			49	Design / retrofit turbines to inject pure oxygen into releases	?	?	?	?
			50	oxygenate water early below dam, such as through creation of riffle sequences	~	++	++	++
	Release of water with heavy metal and nutrient pollution	***Sheet 6***	***51***	De-stratification devices to prevent reduction of nutrients and metals at the sediment surface (also see ***71***)	++	++	++	++
			52	Bio-manipulation (also see ***70***)				
			53	Sediment removal (also see ***72***)	++	+/-	+/-	+/-
Management of the dam	***Sediment Management - too much sediment***	***Sheet 7***	***54***	introduce buffer zones upstream and/or by inlet point to prevent entry of sediment into water course / impoundment	+/-	++	++	+
			55	introduce sedimentation area near inflow or outflow of reservoir	+/-	++	+	+
			56	install sluices to allow controlled release of sediments	+/-	+	+	+
			57	time sediment release to avoid conflict with fish spawning	~	~	~	++
			58	clean gravel using potable suction devices	~	~	-	++
			59	clean gravel using flushing flows	+	+	+	+
			60	Draw down and remove sediment from behind the dam (dispose)	+/--	+/--	+/--	+/--
	Sediment Management - too little sediment downstream	***Sheet 7***	***61***	Place sediment from behind the dam on bankside downstream (to contribute to sediment load)	?	?	?	?
			62	Place alternative sediment source on bankside downstream of dam (to contribute to sediment load) (take care to ensure sourced within catchment and / or has the appropriate physical, chemical and biological attributes)	?	?	?	?
	Fish entrainment into intakes (turbines)	***Sheet 8***	***63***	Divert fish so they do not enter the turbine (eg. embedded pipe-screen diversion, alternative channel etc.)	~	~	~	++
			64	Introduce behavioral barriers (number of alternatives including strobe lights, electrical current, bubble screen, acoustic barriers)	~	~	~	++
			65	introduce physical screens (number of alternatives including horizontal flat plate, trash rack etc)	~	~	~	++
		Sheet 8 & 6	***66***	introduce 'fish-friendly' turbines to reduce injury resulting from mechanical damage, pressure changes, shear stress and turbulence when passing through the turbines	~	~	~	+

Driving force	Pressure	Sheet No.	Tech.No.	Mitigation technique	Impact on WFD indicator Species			
					Phytoplankton	Macrophytes and phytobenthos	benthic invertebrates	fish fauna
Management of the reservoir	*Eutrophication*	*Sheet 5*	*67*	Install destratification devices to prevent the reduction of nutrients at the (anoxic) sediment surface and to circulate algal blooms	++	+	+	+
			68	Provide chemical treatment to the impoundment	++	+	+/-	+
			69	Increase flushing to reduce the residence time	++	+	+	+
			70	Implement bio-manipulation techniques	++	+	+	++
			71	Provide sediment capping to prevent movement of nutrients and pollutants back to the water column under anoxic conditions	++	+	+	+
			72	Remove nutrient rich and / or polluted sediments and dispose	+/-	+/-	+/-	+/-
			73	Implement catchment control techniques (see measures 109 to 116)	++	+	+	+
			74	Implement inlet control measures	++	+	+	+
	Engineering/ (intensive) maintenance of reservoir shoreline (beach, housing, steep shorelines etc)	*Sheet 4*	*75*	Restore shoreline to natural state: remove concrete siding / development	+	++	++	+
		Sheet 4	*76*	Remove undesirable plant and animal species	+	+	+	+
		Sheet 4 & 5	*77*	Restore shoreline to natural state: re-create gradual slope, provide the appropriate physical media and plant native macrophytes	+	+	+	+
		Sheet 4	*78*	Hypolimnetic aeration to improve oxygen levels in the impoundment (eg. Helixors, oxgen injection, air bubblers etc.)				
		Sheet 4	*79*	Create low-level areas for flooding	+/-	+	+	~
		Sheet 4 & 5	*80*	Draft and implement maintenance plan which optimises shore zone (macrophyte) vegetation development	+	++	+	+
		Sheet 4	*81*	Install floating islands of vegetation	~	++	~	+
	Excavation within reservoir		*82*	introduce bunded areas to retain water within defined areas of the reservoir (usually adjacent to the shore) (also see measure 34)	+	+	+	+
			83	Excavate pools in the littoral zone to retain water when reservoir water levels drop (also see measure 35)	+	+	+	+
Management of the reservoir	*Fish stocking*	*Sheet 10*	*84*	Regulate fish stocking	?	?	+	++/-
			85	Tailormade feeding program for stocked fish to prevent overfeeding				
			86	Complete removal of non-native species from riparian and/or reservoir system		+++	+	+++
			87	Install screens or barriers to prevent spreading of non-native (fish) species from impoundment to downstream (see measures 78 to 79)	~	~	~	+
			88	Provide signs and liaise with angling associations to prevent the use of live bait for fishing	?	?	?	++
			89	Provide signage explaining to people why they must not drop plant material from garden ponds and aquaria into the natural watercourse	?	++	?	?
	Recreation, boating, control of hydrocarbon input (PAH)	*Sheet 9*	*90*	Zoning: provide and regulate a *spatial zoning* system to balance recreation and wildlife needs (designate area's as "no entry" to boats)	~	+	+	++
			91	Zoning: provide and regulate a temporal *zoning* system to balance recreation and wildlife needs (control time of year when boating / access is acceptable)	~	+	+	+
			92	Identify approved boat mooring areas and control use of non-approved areas	~	+	+	++
			93	Install (floating) barriers to reduce wave erosion on the shoreline	~	++/-	+/-	++/-
			94	Restrict or prevent use of motorised boats (to control / reduce inputs of hydrocarbons - PAH's)	?	?	+	++
		Sheet 5 and 4	*95*	Provide facilities for emptying toilets from boats and providing toilet facilities for visitors	+	+	+	+
		Sheet 9	*96*	Control access to the littoral zone	~	+	?	+
			97	Provide dam release for white-water rafting / canoeing recreation	+/-	+/-	+/-	++/-

Driving force	Pressure	Sheet No.	Tech.No.	Mitigation technique	Impact on WFD indicator Species			
					Phytoplankton	Macrophytes and phytobenthos	benthic invertebrates	fish fauna
Management of river/streams	***Reduced river channel meandering***	***Sheet 1***	***98***	Restore the riparian habitat (create meanders, ripples, diverse substrate etc)	~	++	++	++
			99	Reinstate a source of sediment for natural transporation down the river system (eg. Measures 61 and 62)	~	++	++	++
	Development of floodplains along river	***Sheet 1***	***100***	Restore floodplain where possible and restore the riparian habitat	~	+++	+++	+++
			101	Designate and manage buffer zones between development and river	+	+	+	+
			102	Provide a controlling impoundment downstream	~	++	++	++
			103	Provide a controlling impoundment on the bankside	~	++	++	++
		Sheet 1 and Sheet 5	***104***	Provide / manage a 'sacrificial' impoundment upstream - managed solely to provide the environmentally acceptable flows for the river system downstream (and not required for the economic use of the primary impoundment(s) - eg. Hydropower or water supply)	~	++	++	++
			105	Provide refugia away from the main flow	~	++	++	++
			106	Water management plan for management of the river system	+++	+++	+++	+++
	Angling	***Sheet 9 and 10***	***107***	Regulate fish stocking	?	?	?	++
			108	Restrict / manage fishing areas (zoning and use of angling tickets)	?	?	?	++
Management of the catchment	***Agricultural use / development of reservoir catchment***	***Sheet 4 and 7***	***109***	Implement catchment management for erosion control (numerous alternatives, case-specific)	++	++	++	++
		Sheet 4	***110***	Implement catchment management for nutrient control (numerous alternatives, case-specific)	+++	++	++	++
		Sheet 4 and 7	***111***	Introduce buffer zones upstream and/or by inlet point	++	++	++	++
			112	Create and manage vegetated deltas	++	++	++	++
		Sheet 4	***113***	Provide phosphorus stripping at inlet point	++	++	++	++
			114	(Re)direct inlet flow via (treatment) wetland	++	++	++	++
		Sheet 7	***115***	Introduce and manage a sedimentation area near inflow or outflow of reservoir	++	++	++	++
			116	Draft and implement water quality monitoring program (alternatives are installing automatic apparatus or sampling by hand)	++	++	++	++
Design		***Sheet 1***	***117***	Increase reservior capacity	?	?	?	?
Planning		***Sheet 1***	***118***	Contingency planning for emergency drawdown	?	?	?	?

TABLE 2: INDICATIVE COSTS OF MITIGATION MEASURES AND MANAGEMENT STRATEGIES FOR IMPOUNDMENTS

Driving force	Pressure	Guidance Sheet No.	Mit. Tech. No.	Mitigation technique	Points of departure	Indication of size	Investment costs	Comments on investment costs	Operational costs	Comments on operational costs	Lifetime of the measure	Other effects of the measure	Source of information	Year of information
Physical presence of the dam	*Continuity*	*Sheet 9*	*1*	Filtration to remove particulate organic matter in reservoir										
		Sheet 7	*2*	Introduce fish pass for movement upstream -number of alternatives including:										
				Denil Plain Baffle		0-2m lift	£15-19K per m lift - total per m £40K	Total includes contingency and commissioning					Scottish Water (Q&S3 project)	2002
				Pool and Weir Ladder		>2-20m lift	£25-34K per m lift - total per m £60K	Total includes contingency and commissioning					Scottish Water (Q&S3 project)	2002
				Vertical Slot		1.5-7m lift	£88K per m lift						Scottish Water (Q&S3 project)	2002
				Fish Trap and transportation	special case	> 20m lift	£97K per m total						Scottish Water (Q&S3 project)	2002
				Fish Lock	not suitable for embankment type dams									
				Baffled fish pass			£70K - £190K		£500 / year				EA manual on fish passes	
		Sheet 10	*3*	Flushing of Sediment (constant)										
		Sheet 9	*4*	Controlled release of sediment (timed to avoid impacts on ecology downstream)										
		Sheet 1	*5*	Riparian habitat restoration	1. Reed fringes, 2. new ponds		Coir rolls £100/m Reed: £1,4 / m2		Reed: 10% of investment costs				Arcadis, the Netherlands	2003
		Sheets 1 and 7	*6*	(Re)stocking of (native) fish species	Adult fish (1+ years) stocked lower down river, fry/parr stocked in tributaries	large stretch river (>10km)	20,000 coarse fish (1+ year) stocked annually for five years @ £40k-£50k pa Salmonids approximately £100k pa to run rearing hatchery that will provide approx 40,000 (1+year) fish	Establishing salmonid populations much more expensive (& site specific). Brood stock to be collected from the river (farmed fish should be avoided as they will only return to their natal river). Smolts need to be grown on at least one year before release.	Annual monitoring costs	n/a	25 years		Environment Agency Fish Culture Team	2004
		Sheets 1 and 10	*7*	Capture/release fish as required	1. Coarse fish 2. Salmonid		1. 15 man days capture effort (assuming team of 3) to acquire 1000 fish from same water course = £3000 2. 30 man days capture effort (asumming team of 3) to aquire 100 fish (to establish rearing hatchery = £6000		none		require monitoring		Environment Agency Fish Culture Team	
		Sheet 4	*8*	(Re)planting of native macrophyte species	Setting out submerged aquatic vegetation		Floating islands - £ 300 / standard four booms Pre-planted coir pallets - 1 m2 (four per island) - £ 25 each						Andrea Kelly, Broads Authoirty, Pers. Comm.. April 2002	2002
		Sheet 10	*9*	Introduce fish pass for movement downstream (spillways, drop-structures)	Baffled fish pass	£70,000 - £190,000			£500 / year				EA manual on fish passes	
		Sheet 7	*10*	Removal of weirs	Demolition		£20 per cubic m	Disposal Regs	none	none	n/a	Flow regime	SPONS	
			11	Locate the impoundment off-line	Reservoir								NAR	
		Sheet 9	*12*	Canoe passage for recreational purposes (no. of solutions such as footpath for portage, dry slide or purpose designed white water channel / shute)	Assuming a stepped weir		Similar to stepped fish pass							
			13	Provide lock structure to provide access for larger boats into navigable waters										
	Altered habitat	*Sheet 3*	*14*	Reduce angle of lake sides	Earth works is assumed		£1.5k per excavation / per 50m2		min		30 years			
		Sheet 4	*15*	Plant marginal species			Coir rolls £100/m							

Driving force	Pressure	Guidance Sheet No.	Mit. Tech. No.	Mitigation technique	Points of departure	Indication of size	Investment costs	Comments on investment costs	Operational costs	Comments on operational costs	Lifetime of the measure	Other effects of the measure	Source of information	Year of information
Management of the dam	***Altered flow downstream***	***Sheet 2***	***16***	Raise and lower flow rates gradually (to avoid hydropeaking type flows changes)	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	Possible negative effects on tourism and possible loss of revenues from existing forms of exploitation.		
			17	Set minimum flow rates (*minimum compensation flows* also called *base flows*)	1. Weir 2. Culverts	1. 20m long.	1. £0.5 - 2 k per m length, 2. £0.6 - 2.5 k per m length		min / annual clean out		25 years			
Management of the dam	***Altered flow downstream***	***Sheet 2***	***18***	Set maximum flow rates	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	Possible negative effects on tourism and possible loss of revenues from existing forms of exploitation.		
			19	Provide *freshets* to mimick natural floods (and encourage upstream migration of fish) (also used on recreational rivers for white water rafting)	Scenario stated by Scottish Water for investment round 2006-14: 12% average reduction in output for reservoirs and 80% average reduction in output for lochs to provide water for discharge to maintain river and stream quality under the terms of the WFD (N									
			20	Provide *flushing flows* to replicate major flood events and flush fine sediments out of spawning gravels	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	Possible negative effects on tourism and possible loss of revenues from existing forms of exploitation.		
		Sheet 1	***21***	Provide *environmentally acceptable flows* (imitate natural flow regime)	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	Possible negative effects on tourism and possible loss of revenues from existing forms of exploitation.		
			22	Provide *seasonally variable flows* combined with environmentally acceptable flows	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	Possible negative effects on tourism and possible loss of revenues from existing forms of exploitation.		
			23	Consider *night time releases*										
			24	Controlled spill to meet water demands of biological elements (primarily fish) downstream	Weir / sluice structure		See weit structure above							
			25	Real-time operation to meet water demands of biological elements (primarily fish) downstream										
	Change to river habitat	***Sheet 1***	***26***	Introduce (artificial) meander directly downstream of dam to dissipate energy	1. Gabions, etc.		max £1k /m, min £5		none		25 years			
			27	Introduce buffer zone of deeper water directly downstream of dam to dissipate energy	1. Stilling Basin, 2. Silt Trap		1. approx £1k /m2 plan area.		Silt Trap: Annual Dredging: £20 k pa		50 years			
			28	Create multi-stage channels	Weirs		Similar to fish pass design for pool and weir structures / m high		n/a		25 years			
			29	Physical habitat modification to improve depth and velocity of existing flows										
			30	Riparian habitat restoration (meanders, ripples, substrate etc)	Riffle boards		£0.5 to 1.5 k per 10m length, Dredging:							
			31	Bank protection to prevent erosion	Gabions Baskets Willow Spikes		£50-65 / m3. £150		Planting, etc. n/a		20 years indefinite			
	Altered water level (fluctuation) in reservoir	***Sheet 3***	***32***	Draft and implement water level regulation which meets demands of biological elements, fish spawning in particular (set (seasonal) minimum and maximum water levels and maximum fluctuation) (balance with reservoir functioning requirements)	Consultancy		£5 to 20 k	Procurement	admin		Policy dependant	A high water level is attractive for tourism and makes a large number of recreational activities possible. On the other hand, a high water level can have negative effects on existing forms of exploitation.		
			33	Install water level gauges to monitor water level and control according to pre-determined 'trigger' criteria										
			34	Introduce bunded areas to retain water within defined areas of the reservoir (usually adjacent to the shore)	Embankment		£11 to 15 / m3	Source of Fill	£5 k pa	Inspections	Indefinite			
			35	Excavate pools in the littoral zone to retain water when reservoir water levels drop										
			36	Introduction of fringing reeds and (boating) islands to act as buffer zone	Floats and reeds		Coir rolls £ 100 /m	Maintenance						
	Altered residence time within reservoir		***37***	Increase flushing to reduce the residence time										
	Release of water with altered temperature to downstream	***Sheet 6***	***38***	Utilise surface storage	Dam		£2 to 3 k per sq metre (in elevation)	Design Heavy	Statutory inspections		100 years			
			39	Draw off water at a number of pre-determined levels through use of a multilevel intake structure										
			40	Provide and fully utilise selective level withdrawal structures	Housing valve	7m tall RC	£200 - £500 k	Heavy Design	Maintenance, drawing down	10k per year	50 years			
	Release of water with altered temperature to downstream	***Sheet 6***	***41***	Use of hydropower coolant water to manipulate releases and achieve target temperature (direct heating or cooling of water unlikely to be viable)										

Driving force	Pressure	Guidance Sheet No.	Mit. Tech. No.	Mitigation technique	Points of departure	Indication of size	Investment costs	Comments on investment costs	Operational costs	Comments on operational costs	Lifetime of the measure	Other effects of the measure	Source of information	Year of information
Management of the dam	*Release of water with altered oxygen content to downstream*	*Sheet 6*	***42***	Consider (re)design of outfall to enhance aeration through turbulent flows										
			43	Reduce supersaturation of water with oxygen through modification of the design and operation of turbine structures.										
			44	Hypolimnetic aeration to improve oxygen levels in the impoundment (eg. Helixors, oxgen injection, air bubblers etc.)	Costs dependent on type of system		Pure oxygen submerged chamber: £ 679,000 million Diffuse deep-water oxygenation: £ 679,000 million	Other options are deep pure oxygen U-tube, shallow pure oxygen U-tube, bubble plume oxygenation, pure oxygen on shore pressurized chamber	Pure oxygen submerged chamber: £ 679,000 million Diffuse deep-water oxygenation: £ 679,000 million	Pure oxygen submerged chamber: £ 577 /day Diffuse deep-water oxygenation: £ 679 / day			Marc Beutel, Improving raw water quality with hypolimnetic oxygenation, AWWA 2002 Conference	2002
			45	Provide artificial destratifiers to improve oxygen levels within impoundment										
			46	Draw off water at a number of pre-determined levels through use of a multilevel intake structure										
			47	Provide and fully utilise selective level withdrawal structures										
			48	Design / retrofit turbines to inject atmospheric air into releases										
			49	Design / retrofit turbines to inject pure oxygen into releases	?									
			50	Oxygenate water early below dam, such as through creation of riffle sequences	?									
	Release of water with heavy metal and nutrient pollution	*Sheet 6*	***51***	De-stratification devices to prevent reduction of nutrients and metals at the sediment surface (also see ***71***)										
			52	Bio-manipulation (also see ***70)***	Assuming fish removal		only operational costs		Routine fish spawning control, removal and survey - £ 500/day Wiring up and processing data - £ 200-300/day Fish-proof barriers - £ 142/12 m section (2-2.5 m depth)				Andrea Kelly, Broads Authority, pers. Comm., April 2001	2002
			53	Sediment removal (also see ***72***)	Sediment removal without draw-down (dreding)		only operational costs		£ 3,50/m3 for direct dredging and transport costs (all types of floating plant) £ 1,-/m3 for spreading of material after de-watering				Vernon et al.	2002
	Sediment Management - too much sediment	*Sheet 7*	***54***	Introduce buffer zones upstream and/or by inlet point to prevent entry of sediment into water course / impoundment	Green Dam		£5k /m	Design, permits	min		indefinite			
			55	Introduce sedimentation area near inflow or outflow of reservoir	Silt Trap									
			56	Install sluices to allow controlled release of sediments	Sluice Gates		£10 to £ 200 k (5 k per gate and 15k per m high)	Design, permits	£15 k pa	Dedicated body	50 years			
			57	Time sediment release to avoid conflict with fish spawning	?									
			58	Clean gravel using potable suction devices	?									
			59	Clean gravel using flushing flows										
			60	Draw down and remove sediment from behind the dam (dispose)										
	Sediment Management - too little sediment downstream	*Sheet 7*	***61***	Place sediment from behind the dam on bankside downstream (to contribute to sediment load)										
			62	Place alternative sediment source on bankside downstream of dam (to contribute to sediment load) (take care to ensure sourced within catchment and / or has the appropriate physical, chemical and biological attributes)										
	Fish entrainment into intakes (turbines)	*Sheet 8*	***63***	Divert fish so they do not enter the turbine (eg. embedded pipe-screen diversion, alternative channel etc.)										
			64	Introduce behavioral barriers (number of alternatives including strobe lights, electrical current, bubble screen, acoustic barriers)										
			65	introduce physical screens (number of alternatives including horizontal flat plate, trash rack etc)	Trash Screens	50m 2 plan area	£200 K	Permits	£20 k pa	Maintenance Dependant	25 years			

Driving force	Pressure	Guidance Sheet No.	Mit. Tech. No.	Mitigation technique	Points of departure	Indication of size	Investment costs	Comments on investment costs	Operational costs	Comments on operational costs	Lifetime of the measure	Other effects of the measure	Source of information	Year of information
Management of the dam	***Fish entrainment into intakes (turbines)***	***Sheet 8 & 6***	***66***	introduce 'fish-friendly' turbines to reduce injury resulting from mechanical damage, pressure changes, shear stress and turbulence when passing through the turbines	?									
Management of reservoir	***Eutrophication***	***Sheet 5***	***67***	Install destratification devices to prevent the reduction of nutrients at the (anoxic) sediment surface and to circulate algal blooms										
			68	Provide chemical treatment to the impoundment		1,500,000 gallons (7,000,000 litres)	£500 chemicals 10 man days = £2500 - 3500	Should not treat more than 25% of water body at any one time and leave for at least 1 week before treatment of other areas. Should be employed with aeration techniques to avoid fish kills			1 year		Cellpharm bioactive prodcuts (www.biosynthesis.co.uk)	
			69	Increase flushing to reduce the residence time										
			70	Implement bio-manipulation techniques										
			71	Provide sediment capping to prevent movement of nutrients and pollutants back to the water column under anoxic conditions										
			72	Remove nutrient rich and / or polluted sediments and dispose										
			73	Implement catchment control techniques (see measures 109 to 116)										
			74	Implement inlet control measures										
	Engineering/ (intensive) maintenance of reservoir shoreline (beach, housing, steep shorelines etc)	***Sheet 4***	***75***	Restore shoreline to natural state: remove concrete siding / development	Demolition and excavations / embankments		£20 / m3 for demolition and £15 / m3 embankments							
			76	Remove undesirable plant and animal species										
		Sheet 4 & 5	***77***	Restore shoreline to natural state: re-create gradual slope, provide the appropriate physical media and plant native macrophytes	Excavation		Up to £20 /m3.							
		Sheet 4	***78***	Hypolimnetic aeration to improve oxygen levels in the impoundment (eg. Helixors, oxgen injection, air bubblers etc.)										
			79	Create low-level areas for flooding	Excavation		£ 2.5 k per area							
		Sheet 4 & 5	***80***	Draft and implement maintenance plan which optimises shore zone (macrophyte) vegetation development	Consultancy work		Up to £20k							
		Sheet 4	***81***	Install floating islands of vegetation										
	Excavation within reservoir	***Sheet 4***	***82***	introduce bunded areas to retain water within defined areas of the reservoir (usually adjacent to the shore) (also see measure 34)	Dredging		£5 / m3 plus at least £8000							
			83	Excavate pools in the littoral zone to retain water when reservoir water levels drop (also see measure 35)										
	Fish stocking	***Sheet 10***	***84***	Regulate fish stocking		large stretch of river up and downstream of reservoir >10km	20,000 coarse fish (1+ year) stocked annually for five years @ £40k-£50k pa Salmonids approximately £100k pa to run rearing hatchery that will provide approx 40,000 (1+year) fish	Establishing salmonid populations much more expensive (& site specific). Brood stock to be collected from the river (farmed fish should be avoided as they will only return to their natal river). Smolts need to be grown on at least one year before release	Annual monitoring costs	n/a	25 years		Environment Agency Fish Culture Team	2004
			85	Tailormade feeding program for stocked fish to prevent overfeeding	?			Not advised. If water course has been sufficiently improved (habitat, flow etc) then should sustain fish populations. Should not stock fish into poor habitat otherwise						

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Management of reservoir	***Fish stocking***	***Sheet 10***	***86***	Complete removal of non-native species from riparian and/or reservoir system	Netting or electrofishing (assume 4 man team)	River up to 2m deep (300m2) Deeper watercourse or reservoir	Assume 2 days work = approx £2400 Unless waterbody is drained will be impossible to ensure all non-natives captured				Forever	Removing a trophic layer may have implications on existing biodiversity (if natives are not replaced in the same season)		
			87	Install screens or barriers to prevent spreading of non-native (fish) species from impoundment to downstream (see measures 65)	Trash Screen - see above									
			88	Provide signs and liaise with angling associations to prevent the use of live bait for fishing										
			89	Provide signage explaining to people why they must not drop plant material from garden ponds and aquaria into the natural watercourse										
	Recreation, boating, control of hydrocarbon input (PAH)	***Sheet 9***	***90***	Zoning: provide and regulate a *spatial zoning* system to balance recreation and wildlife needs (designate area's as "no entry" to boats)	Sinage									
			91	Zoning: provide and regulate a temporal *zoning* system to balance recreation and wildlife needs (control time of year when boating / access is acceptable)	?									
			92	Identify approved boat mooring areas and control use of non-approved areas	?									
			93	Install (floating) barriers to reduce wave erosion on the shoreline	?									
			94	Restrict or prevent use of motorised boats (to control / reduce inputs of hydrocarbons - PAH's)										
		Sheet 5 and 4	***95***	Provide facilities for emptying toilets from boats and providing toilet facilities for visitors										
		Sheet 9	***96***	Control access to the littoral zone										
			97	Provide dam release for white-water rafting / canoeing recreation										
Management of river/streams	***Reduced river channel meandering***	***Sheet 1***	***98***	Restore the riparian habitat (create meanders, ripples, diverse substrate etc)	See above									
			99	Reinstate a source of sediment for natural transporation down the river system (eg. Measures 61 and 62)										
	Development of floodplains along river	***Sheet 1 and Sheet 5***	***100***	Restore floodplain where possible and restore the riparian habitat (as for measure 98)	See above									
			101	Designate and manage buffer zones between development and river										
			102	Provide a controlling impoundment downstream										
			103	Provide a controlling impoundment on the bankside										
			104	Provide / manage a 'sacrificial' impoundment upstream - managed solely to provide the environmentally acceptable flows for the river system downstream (and not required for the economic use of the primary impoundment(s) - eg. Hydropower or water supply)										
			105	Provide refugia away from the main flow										
			106	Water management plan for management of the river system										
	Angling	***Sheet 9 and 10***	***107***	Regulate fish stocking	Need to avoid over-stocking often associated with fisheries									
			108	Restrict / manage fishing areas (zoning and use of angling tickets)	see above									
Management of the catchment	***Agricultural use / development of reservoir catchment***	***Sheet 4 and 7***	***109***	Implement catchment management for erosion control (numerous alternatives, case-specific)	Consultancy		UP TO £20K							
		Sheet 4	***110***	Implement catchment management for nutrient control (numerous alternatives, case-specific)	Consultancy		UP TO £20K							
		Sheet 4 and 7	***111***	Introduce buffer zones upstream and/or by inlet point	See above									
			112	Create and manage vegetated deltas										

Driving force	Pressure	Guidance Sheet No.	Mit. Tech. No.	Mitigation technique	Points of departure	Indication of size	Investment costs	Comments on investment costs	Operational costs	Comments on operational costs	Lifetime of the measure	Other effects of the measure	Source of information	Year of information
Management of the catchment		***Sheet 4***	***113***	Provide phosphorus stripping at inlet point	Phosphate stripping at buffer zones/strips (creating/maintaining undeveloped strip of land between catchment and lake)		£ 123 - £ 163 / hectare (depending on whether contractors or farmers carry out work)						Leeds-Harrison et al.	1996
			114	(Re)direct inlet flow via (treatment) wetland	See above									
		Sheet 7	***115***	Introduce and manage a sedimentation area near inflow or outflow of reservoir	See above									
			116	Draft and implement water quality monitoring program (alternatives are installing automatic apparatus or sampling by hand)	Consultancy		UP TO £20K							
Design		***Sheet 1***	***117***	Increase reservoir capasity										
Planning		***Sheet 1***	***118***	Contingency planning for emergency draw down										