European Commission

JRC TECHNICAL REPORTS

Working Group ECOSTAT report on Common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies

Part 1: Impacted by water storage

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2016

EUR 28413 EN

Joint Research Centre

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JRC Science Hub
https://ec.europa.eu/jrc

JRC103830

EUR 28413 EN

Print	ISBN 978-92-79-64993-6	ISSN 1018-5593	doi:10.2760/722208
PDF	ISBN 978-92-79-64994-3	ISSN 1831-9424	doi:10.2760/649695

Luxembourg: Publications Office of the European Union, 2016

How to cite: Halleraker et al, *Working Group ECOSTAT report on common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies - Part 1: Impacted by water storage*; EUR 28413; doi:10.2760/649695

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Invaluable support was provided by Ecologic Institute funded by the Norwegian Environment Agency (2015/16) and DG Environment of the European Commission (2016). The pictograms illustrating the different mitigation measures relevant for water storage in the report were prepared by Planungsbüro Koenzen with funding provided by the Norwegian Environment Agency. The pictograms may be downloaded for further use from CIRCABC.

We wish to thank all national experts on good ecological potential (GEP) who were nominated by their countries to complete the Mitigation Measures Template for water bodies impacted by water storage. Their responses to the templates served as the main source of information for this report. We also wish to thank all members of the Working Group ECOSTAT of the Common Implementation Strategy of the Water Framework Directive for their comments and suggestions to improve the different report versions.

The picture on the reservoir for dampening flow at the hydropower plant Innertkirchen in Switzerland was kindly provided by Dr. Markus Zeh. This reservoir allows for substantial dampening in the flow falling and ramping rates and in turn considerable reduction in stranding risk for juvenile trout and in macroinvertebrate drift (see Tonolla *et al*. 2017).

Abstract

Hydromorphological alterations for water storage are among the most widespread pressures on water bodies in Europe. Because of the importance of the water uses relying on water storage, such as hydroelectricity generation and public water supply, many of the affected water bodies have been designated as heavily modified. However, in a substantial number of these water bodies, the effects of the alterations are expected to require some mitigation if good ecological potential (GEP) is to be achieved.

One of the core activities for the CIS WG ECOSTAT between 2013 and 2016 has been to try to compare the ecological quality expected by different countries for water bodies impacted by water storage. The process involved the use of a number of workshops and questionnaires to collect relevant information from European water managers. This report is based on information collected via a template on mitigation measures for water bodies impacted by water storage, which was completed by 23 countries.

The key findings of the exercise are as follows:

- Comparing the mitigation expected for good ecological potential by different countries provided a good basis for identifying similarities and differences between those countries' standards for good ecological potential. It also provided a valuable opportunity for the exchange of information.
- There is a high degree of agreement on the typical impacts on water bodies that can result from the different types of water storage schemes.
- The mitigation measures that the participating countries believe should at least be considered to address the main impacts of water storage schemes are similar.
- In all cases, countries design their mitigation measures with the aim of improving ecological quality.
- The most common impacts that countries seek to mitigate so far are impacts on upstream and downstream fish migration.
- The second most common impacts based on mitigation measures analysis are low flow conditions.
- There is a high degree of agreement that providing minimum environmental flow to rivers downstream of dams is an ecologically effective mitigation measure. Among most countries for which information was available, differences in the sizes of the minimum flows considered appropriate are small.
- The most common reasons for ruling out mitigation measures are on the basis of technically infeasibility or significant adverse effects on the benefits provided by the water use. There is general agreement that mitigation measures involving (a) restricting the degree of water-level draw-down in reservoirs and (b) providing minimum environmental flow to rivers downstream of dams have a greater effect on water storage schemes than other mitigation.
- Some but not all countries have so far set minimum requirements for GEP. These minimum requirements aim at ensuring a basic level of ecosystem functioning and, if relevant, continuity for fish.
- There remain differences in the degree of development and refinement of methods for mitigating impacts from water storage, and in the experience of implementing those methods for optimising mitigation measures. The exercise was able to identify emerging good practice. This is described in the main report and we hope will provide a valuable resource for knowledge exchange between countries as they seek to refine and improve their methods.

Suggested next steps
Several critical issues need further clarification as they seem not to be sufficiently covered in existing WFD guidance. It is recommended that the following should be addressed as part of a follow up exercise:

1. Information exchange to improve understanding of:
   - how countries determine the level of significance of adverse effects of measures on use (e.g. hydropower, water supply) and, hence, at which further mitigation is ruled out;
   - how countries distinguish between ruling out measures required for GEP and setting less stringent objectives (e.g. moderate or worse potential); and
   - the typical scales of ecological impact (including in spatial terms) resulting from hydromorphological alterations beyond which countries require measures to be considered to achieve GEP.

2. To further develop understanding of comparability by:
   - selecting cases of rivers/lakes (theoretical or existing ones) which are impacted by water storage and where alterations of hydromorphological conditions, biological impacts and adverse effects on uses are described with sufficient data and
   - assessing the (minimum) conditions that would be expected for GEP using each country's method, including outruling of relevant measures.

1 Introduction

1.1 Scope of the report

This technical report documents the outcome of information exchange on good ecological potential carried out between 2013 and 2016, as a first step towards harmonising/intercalibrating ecological potential in the context of the WFD intercalibration exercise. Following a general introduction the report focuses on the use of mitigation measures for reaching good ecological potential (GEP) for heavily modified water bodies impacted by water storage for hydropower generation, water supply, irrigation and recreation. In addition, it should be mentioned that in some countries the water storage facilities have multipurpose use. The outcome of the information exchange which took place in parallel on heavily modified water bodies (HMWB) impacted by flood protection and drainage will be presented in a separate technical report.

1.2 Key principles – Heavily Modified Water Bodies and Ecological Potential

Several key principles, conclusions and recommendations from Common Implementation Strategy (CIS) guidance and related CIS workshops on HMWBs are still highly relevant in the context of a common understanding on the use of mitigation measures, HMWBs designation and objective setting. The most important key principles are summarised in the following paragraphs.

CIS 2003 Guidance no. 4 on HMWB: The 2003 CIS guidance no. 4 on heavily modified water bodies (WFD CIS, 2003) specifies a common understanding for the designation and classification of HMWBs (Figure 1) and defining good ecological potential (GEP) based on the biological quality elements. Since 2005, a number of CIS workshops have led to key conclusions and recommendations for best management practice for hydromorphology (hymo) issues (available at CIRCABC).

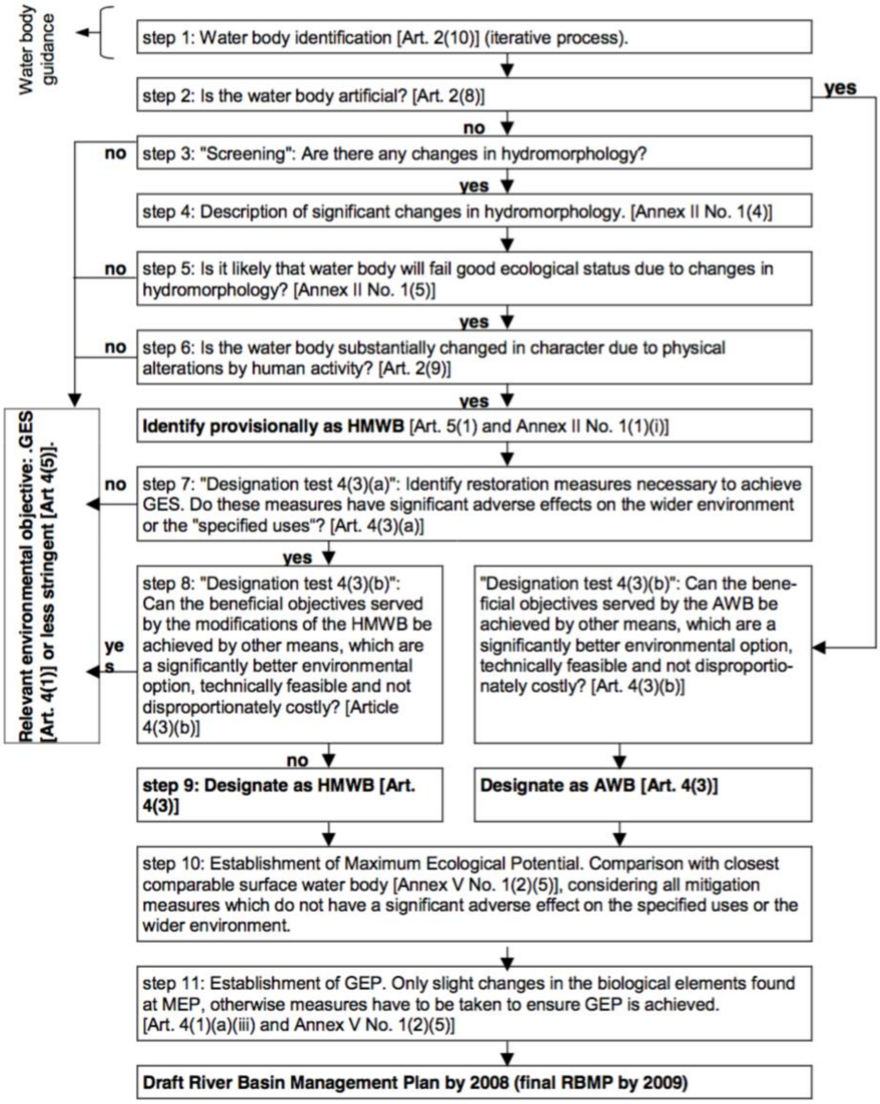

Figure 1. Steps of designation and classification of heavily modified (HMWB) and artificial water bodies (AWB) (from WFD CIS Guidance no. 4 on HMWBs, 2003)

CIS 2005 (Workshop on Hydromorphology): The Prague or the mitigation measure approach was agreed at the CIS workshop on Hydromorphology in 2005 as a valid method for defining GEP (Kampa and Kranz, 2005). The Prague or the mitigation measure approach bases the definition of GEP on the identification of mitigation measures. Starting from all measures that do not have a significant adverse effect on the water use (which reflects maximum ecological potential MEP), those measures are excluded that, in combination, are predicted to deliver only slight ecological improvement. GEP is then defined as the biological values that are expected from implementing the remaining identified mitigation measures. The main difference to the reference-based approach described in the CIS Guidance No 4 is that GEP is derived from the mitigation measures for maximum ecological potential and not from the biological quality element (BQE) values at maximum ecological potential. Both methods define BQE values for GEP.

Both CIS 2003 and CIS 2005 state that GEP is not a “stand alone” objective, but is based on the mitigation measures in relation to the water use. It was therefore proposed to develop lists of relevant mitigation measures along with estimations of their effectiveness.

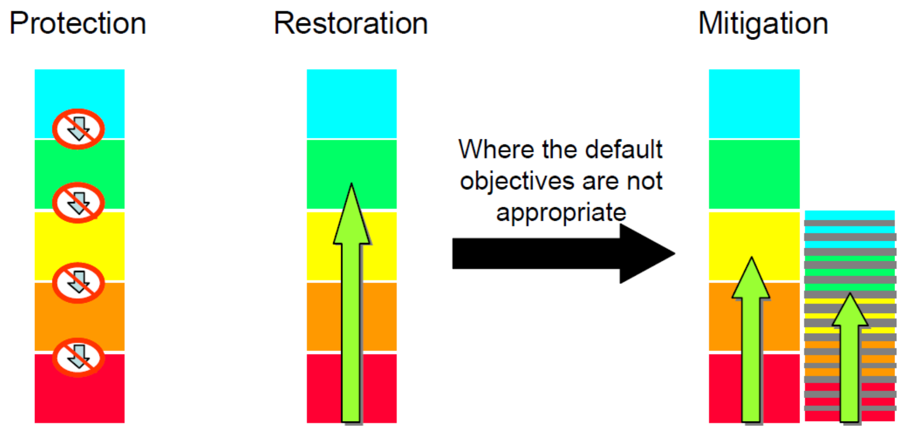

Figure 2. Mitigation measures and Good Ecological Potential (from Kampa and Kranz, 2005)

CIS 2007 (Workshop on WFD & Hydropower): In this workshop and when discussing "Technical approaches for good practice in hydropower use", it was stated that "Standardisation at European level is desirable, but solutions for mitigation measures will have to be largely site-specific. Exchange of information should be promoted on standards that have been developed by different countries or organisations (e.g. for continuity)."

CIS 2009 (Workshop on HMWBs): Regarding significant adverse effect on use, it was agreed, it cannot mean "no impact on use" (key conclusion – kc 21). It was agreed that ecological continuum is a relevant consideration in defining GEP as well as MEP (kc 32). "There must be fish" – fish (in particular, migratory species) is seen as a good indicator of ecological continuum. There was general agreement at this workshop that providing river continuum for fish migration is normally a necessary component of good ecological potential (kc 33). Ecological quality at GEP may be more similar for some uses than others (kc 53).

CIS 2011 (Workshop on Water management, WFD and Hydropower): In the conclusions from this CIS workshop in 2011 (Kampa et al., 2011), it was among others stated that countries and stakeholders still have much to learn from each other (kc 2), and all countries are seeking to improve the water environment with a minimum impact on renewable electricity generation (kc 4). Further, good practice recommendations for mitigation measures include providing (kc 13):

- An ecologically optimised river flow reflecting ecologically important components of the natural flow regime, including a relatively constant base flow and more dynamic/variable flows.
- Where relevant, effective provision for upstream and downstream migration of fish including sufficient flows.
- Dampening of hydro peaking by, for example, gentle ramping or discharging tailrace flows into a retention basin.

The choice and design of mitigation should take account of relevant site-specific circumstances, in particular the potential for ecological improvement.

CIS 2015 Guidance no. 31 on Eflows: The 2015 CIS guidance on Eflows (flow needed for reaching at least good ecological status) identified a series of overall key indications to tackle some critical aspects linked to the management and restoration of water bodies affected by hydrological pressures. However, the flow needs in HMWBs and thereby for reaching good ecological potential was only briefly mentioned in the Eflows guidance

(WFD CIS, 2015), with reference to the ongoing activity on ecological potential under WG ECOSTAT.

1.3 Intercalibration of ecological status and potential

Intercalibration is a process aimed at achieving comparable good status and potential classification boundaries for the biological quality elements set in compliance with the WFD requirements. The requirement for intercalibration is specified in WFD Annex V 1.4.1. The intercalibration exercise is to be carried out by the Member States and facilitated by the Commission, with a deadline set for 2007. Intercalibration activities started soon after the WFD came into force in 2000, as a key activity under the Common Implementation Strategy (CIS). In practice the intercalibration exercise proved to be much more complicated than originally foreseen; by the 2007 deadline only a part of the work could be completed, and a second and even a third phase were necessary. Several CIS guidance documents describe the common understanding and agreed procedures:

- CIS Guidance No. 6 "Towards a guidance on establishment of the intercalibration network and the process of the intercalibration exercise (2003)
- CIS Guidance No. 14 "Guidance on the intercalibration process 2004-2006" (2005)
- Updated CIS Guidance No. 14 "Guidance on the intercalibration process 2008-2011" (2011)
- CIS Guidance No. 30 "Procedure to fit new or updated classification methods to the results of a completed intercalibration exercise (2015)

During phase 1 (finalised in 2007) and phase 2 (2008-2011) the intercalibration exercise has focused on natural water body types[1], and the intercalibration guidance documents do not cover ecological potential: *"As in Phase 1, intercalibration in Phase 2 will focus on […] good ecological status. Good ecological potential (GEP) will not be intercalibrated […]in Phase 2 due to the complexity of defining GEP and the fact that the procedure how to intercalibrate GEP is not yet clear"* (CIS Guidance No. 14).

For natural waters, it has been possible to agree on a technical intercalibration process where Member States' classification methods are checked for their compliance with the normative definitions specified in WFD Annex V. Subsequently, the high-good and good-moderate boundaries are compared and harmonised either directly or by using a common metric. A common understanding of the type-specific reference conditions is a key prerequisite to carry out the comparability analysis for good status classification methods. An important part of intercalibration of natural waters has been to apply/agree on common criteria for reference conditions. Results of the completed intercalibration exercises were published in COM Decisions 2008/915/EC (phase 1) and 2013/480/EU (phase 2). The current phase 3 (2012-2016) is aimed at completing intercalibration (IC) gaps for natural water body types, and to start addressing ecological potential.

The WFD specifies that for maximum ecological potential, "the values of the relevant biological quality elements [should] reflect, as far as possible, those associated with the closest comparable surface water body type, given the physical conditions which result from the artificial or heavily modified characteristics of the water body" (WFD Annex V 1.2.5). Intercalibration is ultimately about achieving comparability for good status and potential classification boundaries for the biological elements. The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories above most closely resembles the heavily modified or artificial water body concerned (WFD Annex V 1.1.5).

[1] An exception is the biological quality element phytoplankton as an indicator for the effects of nutrient pressure that has been intercalibrated for Mediterranean reservoirs

It is not possible to apply the intercalibration procedures that were developed for the natural water body types to heavily modified water bodies. The main reason is that setting good ecological potential boundaries for the biological quality elements can not be seen separately from the HMWB designation process (Figure 1). This is further emphasized in WFD definition of maximum ecological potential for the hydromorphological elements, i.e. "The hydromorphological conditions are consistent with the only impacts on the surface water body being those resulting from the artificial or heavily modified characteristics of the water body once all mitigation measures have been taken to ensure the best approximation to ecological continuum, in particular with respect to migration of fauna and appropriate spawning and breeding grounds" (WFD Annex V 1.2.5).

CIS ECOSTAT 2011 (Concept paper on Intercalibration of GEP): This concept paper endorsed by the Water Directors, discusses possibilities for intercalibrating good ecological potential in accordance with WFD requirements and provides recommendations on assessing and improving comparability of good ecological potential assessments. A comprehensive intercalibration of GEP in the same form as undertaken for good ecological status is not expected to be technically possible. The reasons for this are that:

- Member States' definitions of good ecological potential will always be influenced by their national judgements about the significance, and hence acceptability, of adverse effects on the use (e.g. water storage for hydropower) or on the wider environment;
- Scientific understanding of the ecological impact of hydromorphological alterations is less well developed than is the understanding of the impact of pollution;
- There is considerable variability in the nature and extent of hydromorphological alterations because of the wide range of uses for which water bodies have been designated heavily modified and the wide variation in the associated hydromorphological modifications.

Therefore, alternative approaches to assessing and improving comparability are needed. The proposed pragmatic approach had the following three components:

a) review of the current state of play in defining good ecological potential taking into account the requirements of the WFD and existing guidance documents;

b) development of a methodological framework for defining and assessing good ecological potential taking into account the results of the review; and

c) simple comparisons of good ecological potential for common uses.

1.4 Mandate and scope of the information exchange on GEP mitigation measures

As one of the core activities for the CIS working group on Ecological Status (ECOSTAT) since 2013, a harmonised understanding of GEP, often mentioned as intercalibration, for HMWBs has been on the agenda. An ad-hoc group has been working on harmonising GEP mainly related to water storage, consisting of national experts on hymo issues and coordinated by a core group (the authors of this report).

Several information exchange templates have been circulated between Member States and EEA countries to exchange data on ecological indexes sensitive to hydromorphological alteration, available mitigation measures and approaches to defining GEP in relation to water storage. Workshops based on the template results have been arranged to clarify terms and definitions, highlight where there is alignment, and where there are differences in approaches and to start to explore the reasons behind these. Presentations and documents related to the group's work are available on CIRCABC.

The main aims of the information exchange on GEP for HMWBs impacted by water storage have been to:

- exchange experience on good ecological potential (GEP) and hymo alterations caused by specific water uses,
- find suitable methods for assessing comparability (intercalibration),
- learn from each other to ensure common understanding,
- sort out good management practice and
- possibly define best available mitigation measures for heavily modified water bodies due to water storage across Europe.

Working towards these aims, it was agreed that as a first step the following related questions for rivers and lakes hydromorphologically impacted by specific water uses needed to be addressed:

- Do we look at comparable impacts, regarding type and scale?
- Do our national mitigation measure libraries contain comparable measures for these impacts?
- Do we use comparable criteria to select/rule out mitigation measures?
- Do countries have common standards for GEP, and hence is there a uniform ecological minimum across Europe?
- Do countries have the same awareness of the optimal design of hydromorphological measures ensuring GES?

1.5 Relevant water uses for HMWB designation

The relevant water uses for HMWB designation are the water uses described in WFD Article 4(3)(a)(ii)-(v). Based on Member State (MS) questionnaire results, for the purpose of the 2009 CIS workshop on HMWBs, the clarity provided by Member States in the 1st RBMPs about the "use" or "uses" for which they have designated water bodies as heavily modified has been very variable. Several uses such water storage, flood defence and navigation, were clearly specified and in line with Art. 4.3(a) of the WFD. However, several other uses were not as clearly specified or not mentioned in Art. 4(3), such as agriculture, not making clear if it refers to land drainage or other activity. Moreover, the use of the term "equally important sustainable human development activities" has been left open to interpretation.

In addition, in the 1st RBMP cycle, a consistent reporting of the uses (and physical alterations) for which water bodies were designated as heavily modified was not made under the electronic reporting under WISE.

For the assessment of the 1st RBMPs by the European Commission, information was collected on the main uses for which water bodies were designated as HMWBs/AWBs at the RBD level. According to this assessment, water storage for hydropower generation, navigation, flood protection, water regulation and water storage for drinking water supply appeared as the most common uses for designating HMWBs (reported in more than 60% of RBDs which specified the water uses of HMWBs)[2] (CSWD, 2012).

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[2] Note that this does not reflect count of absolute numbers of designated HMWB but qualitative assessment of the usage or not of each respective use as relevant for HMWB designation in the RBD.

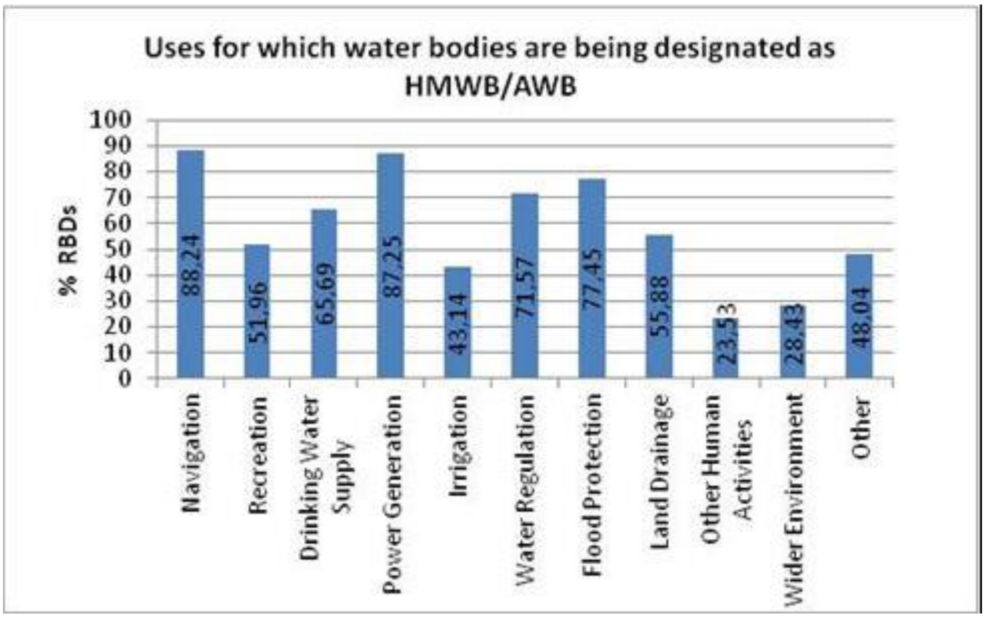


Figure 3. Uses for which water bodies were designated as heavily modified water bodies and artificial water bodies in the 1st RBMPs.

Source: RBMPs, from CSWD 2012

According to the new 2016 WFD reporting guidance (for the 2nd and next RBMPs), it is required to report in detail the water uses for all water bodies designated as HMWBs.

2 Water storage and impacts on water bodies

Dams, abstractions and infrastructures related to water storage may have a severe impact on water ecology if the ecological impacts are not mitigated. Hydromorphological alteration (hymo) and over-abstraction of water in particular, are found to be the second most common pressures on ecological status in the EU (COM 2012). Ecological flows (Eflows) are one of the key issues, with a separate CIS guidance published in 2015.

2.1 Key principles – hydropower and water storage

What is "water storage"?

In the context of this report, water storage is considered to refer to larger structures for impounding water for useful purposes, such as water supply, power generation, irrigation and recreation, especially by abstraction intakes and dams in rivers or lakes/reservoirs for permanent longer term (days – interannual) storage of surface water. Due to water storage by dams many rivers or even brook valleys may change water category from river/brook to larger lake reservoirs. In these cases, it is necessary to apply a limnological approach to take the change in character adequately into account.

Taking into account CIS-Guidance no. 4 on HMWB designation, physical alterations due to small scale hydropower (without relatively large water storage dams) normally do not fulfill the requirements for HMWB designation.

Typical hydromorphological alterations causing ecological impacts on water bodies from water storage

The most obvious alteration on river ecosystems caused by water storage through dams or weirs with impoundments is a reduced or interrupted river continuity. Therefore, natural sediment dynamic is altered and transport can be totally disrupted, especially of coarse sediments. This leads to changes in substrate composition and altered morphological processes in the river downstream of these structures. The continuity for aquatic organisms can be interrupted both upstream and downstream of barriers. The impacts are particularly significant on migratory species.

Moreover, through reduced flow rates, ponded river reaches can lead to disrupted morphodynamics with e.g. changed substrate conditions (accumulation of fine sediments), artificially stable river banks and reduced lateral erosion processes. This determines major changes in composition of aquatic biota, especially in rivers characterized by chains of ponded reaches and in large impoundments such as reservoirs.

A changed flow regime through reservoirs commonly causes artificially extreme low flows or extended low flows. Loss of or reduction in flows which are sufficient to trigger and sustain fish migration can be the result. In addition, loss, reduction or absence of variable flows, compared to reference conditions, is a major issue. These alterations are in general relevant for different types of reservoirs, but especially in such with water abstraction and transfer that lead to depleted river reaches.

Special hydropower operation can also lead to rapidly changing flows and water level fluctuations (including hydro peaking) downstream of turbine outlet into the river (downstream of tailrace). Among others, this type of management can cause artificially extreme changes in lake level of a reservoir (lake draw down). The results frequently are reductions in quality and extent of shallow water and shore zone habitats in the lake.

Furthermore, especially reservoirs, with totally changed hydromorphological conditions from a riverine to a lake ecosystem, often cause alteration of general physico-chemical conditions downstream, e.g. temperature or super saturation of oxygen. These parameters are not hydromorphological, but describe secondary effects that are induced by the hydromorphological changes and of relevance according to the ecological impacts from water storage.

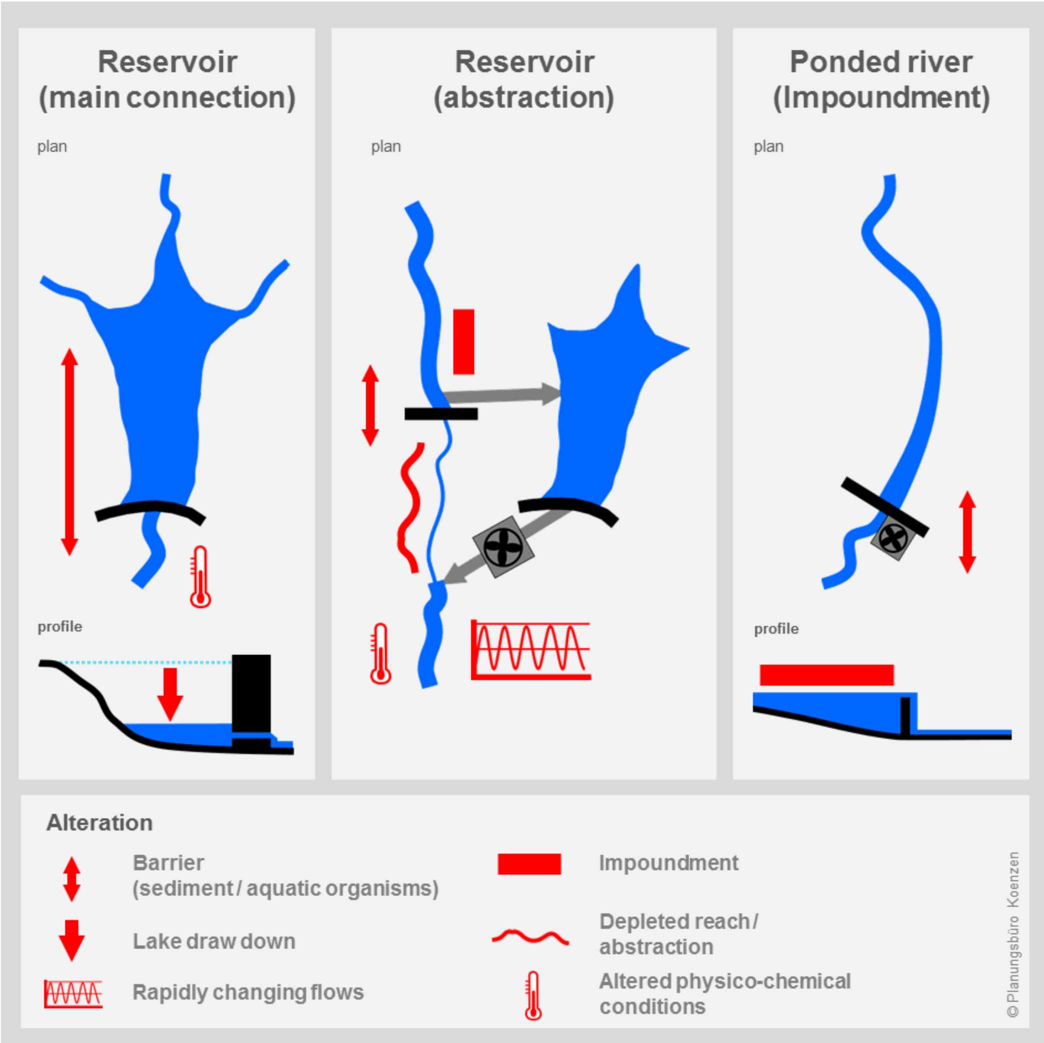


Figure 4. Typical hydromorphological alterations causing ecological impacts on water bodies from water storage (for hydropower, drinking-water supply, irrigation or other equally important sustainable activities as stated in Article 4(3) of WFD).

2.2 Large dams for water storage in Europe

The total European reservoir surface area covers more than 100 000 km^2, 50% of which lies in the European part of Russia. Turkey also has a large number of reservoirs. In WFD implementing countries, the countries with the largest number of reservoirs are Spain (approx. 1200), the UK (approx. 570) and Italy (approx. 570). Other countries with a large number of reservoirs are France (approx. 550), Norway (approx. 364), Germany (approx. 300) and Sweden (approx. 190).

Bakken (2016, in prep) provide an overview of the numbers of reservoirs (large dams) for water storage in European countries. According to this dataset, Malta is the only WFD implementing country in Europe without any large dam/water storage reservoir in the ICOLD database. It needs to be noted that these numbers only refer to large dams, while in many countries, there are many smaller reservoirs exceeding the number of large reservoirs. Hydropower is the dominating single or main purpose water use in multi-purpose reservoirs in Europe, even though irrigation, water supply or flood control is dominating in some of the countries.

Note that for the purpose of inclusion in the World Register of Dams, a large dam is defined as any dam above 15 metres in height (measured from the lowest point of foundation to top of dam) or any dam between 10 and 15 metres in height which meets at least one of the following conditions: a) the crest length is not less than 500 metres; b) the capacity of the reservoir formed by the dam is not less than one million cubic metres; c) the maximum flood discharge dealt with by the dam is not less than 2 000 cubic metres per second; d) the dam had specially difficult foundation problems; e) the dam is of unusual design.[3]

Table 1. An overview of reservoirs (large dams) for water storage in Europe.

						Number of single purpose with this purpose (%)					Number of multi-purpose with this purpose as MAIN purpose (%)							
Country	**Total no of reservoirs**	**Tot single purpose reservoirs**	**Tot multi purpose**	**Tot Unknown**	**% single purp**	**Hydro**	**Irrigation**	**Water suppl**	**Flood control**	**Other**	**Hydro**	**Irrigation**	**Water suppl**	**Flood control**	**Fish Farming**	**Navigation**	**Recreation**	**Other**
Austria	171	127	43	1	74 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Belgium	15	8	7	0	53 %	50 %	0 %	13 %	0 %	38 %	29 %	0 %	43 %	0 %	0 %	29 %	0 %	0 %
Bulgaria	181	156	24	1	86 %	13 %	76 %	10 %	2 %	0 %	46 %	17 %	29 %	8 %	0 %	0 %	0 %	0 %
Croatia	29	14	15	0	48 %	64 %	0 %	7 %	29 %	0 %	67 %	0 %	0 %	33 %	0 %	0 %	0 %	0 %
Cyprus	57	50	7	0	88 %	0 %	92 %	2 %	0 %	6 %	0 %	71 %	29 %	0 %	0 %	0 %	0 %	0 %
Czech Republic	118	52	66	0	44 %	15 %	4 %	60 %	13 %	8 %	15 %	2 %	47 %	33 %	0 %	0 %	3 %	0 %
Denmark	10	10	0	0	100 %	70 %	0 %	30 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Finland	56	47	9	0	84 %	91 %	0 %	4 %	2 %	2 %	11 %	0 %	0 %	89 %	0 %	0 %	0 %	0 %
France	691	438	247	6	63 %	64 %	14 %	13 %	2 %	7 %	21 %	30 %	25 %	6 %	0 %	8 %	8 %	1 %
Germany	308	148	158	2	48 %	22 %	5 %	26 %	36 %	11 %	9 %	0 %	35 %	43 %	0 %	6 %	4 %	3 %
Greece	164	89	61	14	54 %	9 %	67 %	17 %	1 %	6 %	15 %	31 %	41 %	5 %	0 %	0 %	0 %	8 %
Hungary	15	13	2	0	87 %	0 %	8 %	85 %	8 %	0 %	0 %	50 %	0 %	0 %	0 %	0 %	50 %	0 %
Iceland	29	29	0	0	100 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Ireland	16	12	4	0	75 %	50 %	0 %	50 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Italy	542	443	90	9	82 %	69 %	20 %	10 %	1 %	0 %	20 %	43 %	36 %	1 %	0 %	0 %	0 %	0 %
Latvia	3	3	0	0	100 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Lithuania	23	3	20	0	13 %	100 %	0 %	0 %	0 %	0 %	40 %	25 %	0 %	15 %	0 %	0 %	20 %	0 %
Luxembourg	3	2	1	0	67 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Netherlands	12	8	4	0	67 %	0 %	0 %	0 %	75 %	25 %	0 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %
Norway	335	257	2	76	77 %	93 %	0 %	5 %	0 %	2 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Poland	69	21	48	0	30 %	71 %	5 %	19 %	0 %	5 %	27 %	4 %	42 %	17 %	0 %	6 %	2 %	2 %
Portugal	217	157	56	4	72 %	29 %	48 %	18 %	1 %	3 %	14 %	66 %	20 %	0 %	0 %	0 %	0 %	0 %
Romania	246	97	149	0	39 %	70 %	0 %	4 %	25 %	1 %	25 %	17 %	39 %	16 %	2 %	1 %	0 %	0 %
Slovakia	50	15	35	0	30 %	67 %	0 %	33 %	0 %	0 %	14 %	6 %	20 %	57 %	0 %	0 %	3 %	0 %
Slovenia	41	28	13	0	68 %	82 %	0 %	0 %	4 %	14 %	8 %	8 %	0 %	77 %	8 %	0 %	0 %	0 %
Spain	1082	802	270	10	74 %	24 %	35 %	30 %	3 %	8 %	25 %	4 %	59 %	7 %	0 %	0 %	0 %	4 %
Sweden	190	186	3	1	98 %	90 %	0 %	10 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
United Kingdom	607	560	43	4	92 %	15 %	1 %	75 %	1 %	8 %	2 %	0 %	44 %	5 %	0 %	16 %	33 %	0 %

Note 1: Only countries implementing the Water Framework Directive in Europe are included; Data from Bakken (2016 in prep); CIGB ICOLD database. http://www.icold-cigb.org/GB/World_register/general_synthesis.asp

Note 2: Not all stated reservoirs for water storage were designated as heavily modified water bodies (HMWBs) as part of WFD implementation.

2.3 HMWB designation due to hydropower

The figure below shows the percentage of HMWBs designated due to hydropower use in relation to total HMWBs in the 1st RBMPs of the WFD. Taking into account CIS-Guidance no. 4 on HMWB designation, physical alterations due to small scale hydropower (without relatively large water storage dams) normally do not fulfill the requirements for HMWB designation.

SE, NO, FI, CZ and AT have the highest percentage of HMWBs due to hydropower (above 50% of total HWMB).

The NL, DE, UK, LV and IT have the lowest percentage of HMWBs due to hydropower (below 10% of total HMWBs).

[3] Source: http://www.icold-cigb.org/GB/Dictionary/dictionary.asp.

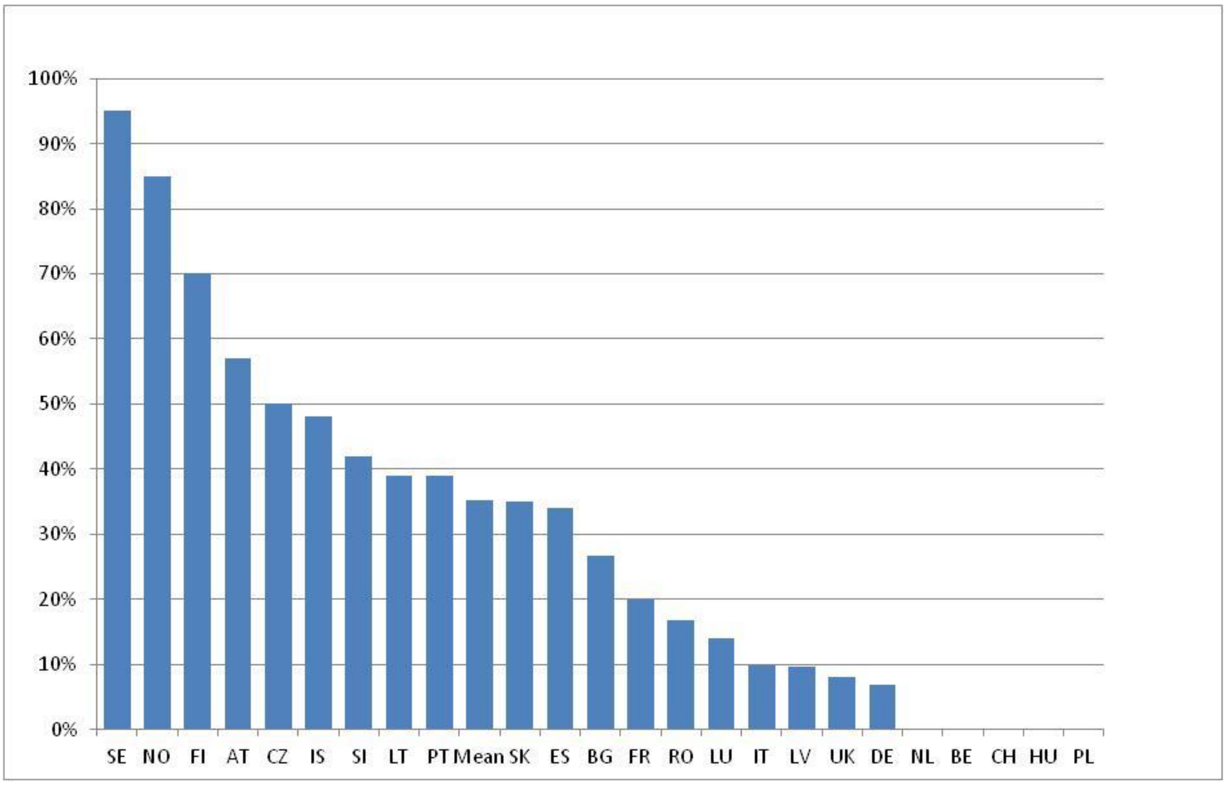


Figure 5. Percentage of HMWBs designated due to hydropower in relation to total HMWBs (%)

Source: Kampa et al. (2011).

Note: 1) Percentages were reported in the WFD and Hydropower questionnaires of European States. 2) Data was not available for CH, BE, HU, PL. 3) The mean is calculated based on the percentages provided in the European States questionnaire.

2.4 Key terms in this report

Key terms used within this report are illustrated below. A more detailed list of relevant hydromorphology-related terms and definitions is available at http://wiki.reformrivers.eu/.[4]

Term	Definition (in the context of this report)
Abstraction	Removal of water from a water body, either permanently or temporarily.
Barrier	Structure across a stream, equipped with a series of gates or other mechanisms which control the water-surface level upstream to regulate the flow or to divert water supplies into another watercourse.
Diversion of water	See water abstraction

[4] REFORM was a large integrated research project (2011-2015) on restoring rivers for effective catchment management.

Term	Definition (in the context of this report)
Ecological effectiveness	Improvement in water ecology from mitigation measures.
Ecological flow (eflow)	CIS-Guidance No 31: Ecological flows are considered within the context of the WFD as "a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)". Considering Article 4(1) of the WFD, the environmental objectives refer to: • non deterioration of the existing status, • achievement of good ecological status in natural surface water body, and • compliance with standards and objectives for protected areas, including the ones designated for the protection of habitats and species where the maintenance or improvement of the status of water is an important factor for their protection, including relevant Natura 2000 sites designated under the Birds and Habitats Directives.
Effect on use	Adverse effect on the water use leads to the designation of HMWBs, here related to significant adverse effect upon the main purpose of water storage such as hydropower, water supply, irrigation or aquaculture.
Hydropeaking	Rapid changes of flow (water level) downstream hydropower stations due to electricity production on demand/short term regulation in the grid.
Impoundment	River water body formed by impounding. A transversal barrier (dam, weir) to the flow in a river impounds water upstream. The purpose of an impoundment usually is to maintain a desired water level (e.g. for electricity production) and/or to retain/store water (e.g. for flood protection, water supply, irrigation). A large impoundment of a natural river is often called reservoir. The hydromorphological character of the river upstream of the dam (impounded/ponded section) is then totally changed from a riverine to a more stagnant character.
Key measures	Categorisation of measures for mitigation used in this report.
Measure hierarchy	Ranking of preference if there is a choice of different mitigation sub-measures application (eg. 1st rank, 2nd rank, 3rd rank, …). If options are not differentiated in terms of preference, all sub-measures are 1st ranked.
Mitigation measure	Physical or biological measure to mitigate ecological effects in an impacted water body (in this context: impacted by water storage) leading to an improvement of the ecological conditions. Compare restoration measure.
Mitigation	Spreadsheet developed to assess comparability by collecting data

Term	Definition (in the context of this report)
Measure Template (MMT)	from each Member State (and Norway) in order to compare approaches for defining good ecological potential, based on national measure libraries.
Ponding	Reference to impoundment – see impoundment
Pressure	The direct environmental effect of a driver (e.g. altered flow conditions, changing water chemistry, organic pollution, water abstraction).
Re discharge of flow	Return of abstracted water after use, typically associated with hydropower, downstream of hydropower outlet.
Reservoir	Large water body built to store water for useful purposes, such as water supply, power generation, irrigation and recreation. It can be • constructed artificially and filled by transferred water • an adapted natural lake • a large impoundment of a natural river Ecologically it resembles a lake type.
Restoration measure	Measure needed to restore natural processes, and hence reach good ecological status, such as e.g. Eflows.
Sub measures	Sub-category of measure mitigating the same hydromorphological pressure or measures needed to combine various types of measures, e.g. to enhance fish migration (ladder, fish way, ramp).
Tailrace	Channel which conducts abstracted water away from turbine (or waterwheel) and by which water usually is re-discharged into a river.
Water (flow) regulation	Water/flow in a river is regulated by water control structures (to manage the hydrological regime by modifying the direction or rate of flow of water, and / or to maintain a desired water surface elevation) or by abstractions/diversions.
Water storage	Impounding water for useful purposes, such as water supply, power generation, irrigation and recreation (includes storage of water in reservoirs as well as damming of rivers).
Water use	See impact on use
Weir	Transversal structure similar to a small dam which may be used for controlling upstream water level and/or sediment load and also for measuring discharge.

3 European questionnaires on mitigation measures for water bodies impacted by water storage

3.1 Overview of mitigation measure template

An essential component of the work on harmonising the understanding of good ecological potential for water bodies impacted by water storage has been information exchange templates to collect and compare data.

An information exchange template was circulated to national experts in countries implementing the WFD (EU Member States and EEA countries) to gather information on national measures available to a country for mitigating ecological impacts from water storage pressures, and how these measures are used. Measures were grouped into 10 key types of mitigation based on the types of water affected (e.g. rivers upstream or downstream of structures), water use (e.g. hydropower, drinking water supply) and pressure (e.g. dam, abstraction).

In a series of Excel worksheets, information was requested on 1) how the mitigation measures are used (is there a formal process and clear criteria in place for not including the measure, or is it left to local discretion?); 2) the significant effect on use; 3) evaluation of GEP (HMWB) vs. GES (natural water body) for water bodies affected by water storage.

For each of the 10 key types of mitigation, national experts were asked to indicate which of the ecological impacts are recognised and addressed by mitigation in the country's lists of mitigation measures, which mitigation measures must be in place to achieve GEP (as long as ecological impact is significant), whether there can be exceptions, and if so, the common reasons for these.

3.2 Specific questions in the mitigation measure template

The following sequence of questions were asked to be filled in for each of the key types of mitigation and their specific measures (options) in the European mitigation measure template, based on information from and use of national measure libraries.

Typical scale of impact for considering mitigation

Countries were asked to fill in the typical minimum scale of impact (length-range of impacted rivers or for lakes lake level fluctuation) for which mitigation would be considered [i.e. adverse impacts on lengths shorter than this typical minimum would not be considered significant in terms of water body classification].

Ranking of measures (options)

A considerable number of measures exist in Europe to mitigate the same main impact from water storage. E.g. interrupted continuity for fish may in some countries be mitigated by a fish pass, by-pass channel, catching and transporting fish, a fish ramp or fish stocking. Where there are multiple mitigating measures within a country's measures library, experts were asked to fill in a ranking (measure hierarchy) to differentiate between 1st, 2nd, 3rd choice etc., according to use, ecological effectiveness and effect on water use.

Ecological effectiveness of measures

Countries were asked to indicate (***) for measures shown to be ecologically effective at a wide range of sites or for measures whose ecological effectiveness is otherwise not the subject to any real doubt; (**) for measures that have been applied at a limited number of sites or their general ecological effectiveness is not yet widely accepted; (*) for measures that have not yet been applied in practice or only in one-off (and not yet conclusive) trials. This section is not asking you to judge, for example, the relative effectiveness of the precise value of the magnitude of a mitigation flow versus the magnitude of slightly different mitigation flow. It was about confidence that the mitigation measure is effective whether or not a higher or lower flow might be even more, or no less, effective, respectively.

Practical effectiveness of measures

At the measure level, national experts were asked to evaluate the practical effectiveness of measures, in relative terms from high (***) for measures shown to be self-sustaining, medium (**) to low (*) for measures that need regular maintenance e.g. annually.

Relative magnitude of effect on water use

Measures assigned "+++" are expected to have a larger effect on the use than other measures in the national list of mitigation measures. It does not mean that the effect on use is significant. Measures assigned "+" are expected to have the least effect on use (other than measures that have no effect on use. For example, providing flow to operate a fish pass during periods of fish migration should normally be assigned "+". In contrast, mitigation that would require major changes in the operation of a reservoir to remedy severe drawdown-related impacts might be among those measures assigned "+++"

How mitigation measure libraries for GEP are used?

In this part of the template, we asked whether there are any fixed rules (e.g. minimum criteria) for implementing or not each of the measures in each country. We also collected information on the most widespread reason for out ruling measures linked to reasons for exemptions in the relevant articles of the WFD.

Effect on use test

The focus in this part of the template is on the country-specific national framework criteria for deciding upon "significant adverse effect on hydropower or water supply" (Art 4.3 in WFD) as basis for ruling out certain mitigation measures. For those countries having a national framework for this, how does it look like (e.g. scheme or national level, % or related to hydropower production), and how has it been developed (public consultation)?

GEP vs. GES

For the final HMWB designation for water bodies affected by water storage, good ecological status (GES) should not be possible to reach. According to the CIS guidance on Eflows (WFD CIS, 2015), the "definition of ecological flow and identification of the necessary measures to deliver it and achieve GES should, where hydrology is significantly altered, be considered as part of the designation test for HMWBs and justify that these measures cannot be taken. Ecological flows are defined as "a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1). In the template, countries were asked: *1) Do you have water bodies affected by water storage reaching or nearly reaching good ecological status (GES)? 2) What do you expect to be the most common reasons for water storage affected water bodies reaching GES?*

3.3 Responding countries

In total, 23 European countries implementing the WFD have provided relevant information or filled in all or part of the template for their country (see Table 2). In addition, 3 countries (HR, IC and SI) have responded that they could not fill in the template due to pending issues e.g. mitigation measure library still under development. 4 countries (BE, EL, LV, PL) have not responded to our template and thereby have not contributed yet to a more common understanding.

In some cases, inconsistencies in answers were identified when evaluating the Mitigation Measures Templates. For example, there are countries indicating that a specific measure or type of mitigation is not included in the national mitigation library but then give details on implementation of this measure in other parts of the template (or vice versa).

Table 2. Overview of responding countries to the knowledge exchange on available mitigation measures and their use (green = MMT completed including use of measures, yellow = MMT incomplete, some relevant information of template not filled in, brown = no country response.

	Completeness of information	**A - Mitigation Overview**	**Filled in measure sheet 1 - 10 (%)**	**B - Use of libraries for GEP**	**C - Frequency of measure use**	**D - impact on use test**	**E - GEP vs. GES**
Austria – AT	OK	x	100	x	x	x	x
Bulgaria - BG	Some gaps	x	100				
Cyprus - CY	OK	x	100	x	x	x	x
Czech Republic - CZ	Some gaps	x	90		x	x	
Estonia - EE	OK	x	100	x	x	x	x
Denmark – DK	OK	x	100	x	x	x	x
Finland – FI	OK	x	100	x	x	x	x
France – FR	OK	x	100	x	x	x	x
Germany - DE	OK	x	100	x	x	x	x
Hungary - HU	Some gaps	x	40		x	x	
Ireland – IE	OK	x	100	x	x	x	x
Italy – IT	(Ok)	x	100	x	x		
Lithuania – LT	OK	x	100	x	x	x	x
Luxemburg – LU	Some gaps	x	100				
Malta* - MT	OK	x	100	n.r.	n.r.	n.r.	n.r.
Netherlands – NL	Some gaps	x	100				
Norway – NO	OK	x	100	x	x	x	x
Portugal - PT	OK	x	100	x	x	x	x
Romania – RO	OK	x	100	x	x	x	x

Slovakia - SK	OK	x	100	x	x	x	x
Spain – ES	OK	x	100	x	x	x	x
Sweden – SE	OK	x	100	x	x	x	x
UK – UK	OK	x	100	x	x	x	
Croatia – HR	No information provided						
Iceland – IC	No information provided						
Slovenia - SI	No information provided						
Belgium – BE	No information provided						
Greece – EL	No information provided						
Latvia – LV	No information provided						
Poland – PL	No information provided						

* *Mitigation of impact from water storage not relevant*.

4 Report structure & content

The purpose of this report is to present the responses of 23 European countries on the Mitigation Measures Template for water storage and draw relevant conclusions on the use of mitigation measures for reaching GEP.

Chapter 5 of the report presents the key types of mitigation for water storage (10 types of mitigation) and the main relevant mitigation measures as well as their use in national libraries of measures.

Chapters 6 to 11 describe the ten key types of mitigation and the relevant mitigation measures in detail, while reflecting on country responses with respect to the use of these measures, their effectiveness and reasons for ruling them out (among others).

Chapter 12 addresses sustainable versus non-sustainable mitigation solutions referring to examples of non-sustainable measures especially fish stocking. Chapter 13 discusses the scale of impacts typically mitigated to reach GEP in the different countries. Chapter 14 presents the country responses on the determination of significant effects of measures on water storage from hydropower and water supply and on the wider environment. Chapter 15 presents the main reasons for outruling measures when defining GEP and chapter 16 addresses minimum requirements for GEP as reported by countries. Chapter 17 summarises the key findings of the report, while chapter 18 draws key conclusions and makes recommendations for further action.

This report is accompanied by a technical annex (separate document available on CIRCABC) which provides the detailed analysis of the mitigation measures templates for water bodies impacted by water storage.

Aspects that have not been specifically addressed in this report

Concerning flow, this report concentrates upon those flow issues which are directly related to water storage and does not refer to all uses leading to flow alterations such as water abstraction by small hydropower plants. It also does not include a detailed discussion on the interdependency between hydrological alterations and morphological conditions as well as type-specific sensitivities; however morphological modifications are dealt with in case of being a relevant, typical measure option for mitigating flow alterations.

Most of the countries delivered information on flow alterations due to hydropower use, but only a few countries with regard to drinking water supply. The templates were focused on these two uses, but it has to be mentioned that in some countries storage facilities/reservoirs are used for multiple purposes.

We are also aware that all relevant mitigation measures that may be needed to fully mitigate (long term) impacts directly or indirectly from water storage are not covered in this report. This is partly due to terminology and/or main focus from a specific mitigation measure. However, management and mitigation dealing with invasive plant species, riparian vegetation or in-channel vegetation are examples of issues specifically not covered, even though they are partly related to sediment management and flow mitigation.

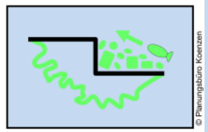
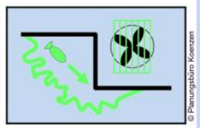
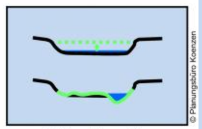
5 Key measures to mitigate impacts from water storage in Europe

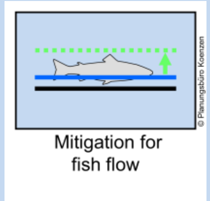
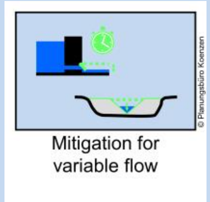
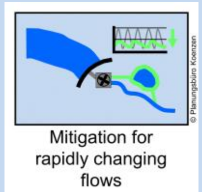
5.1 Overview of key measure types

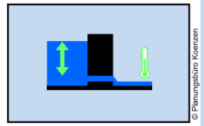
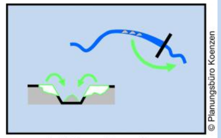
The following Table 3 maps the key types of mitigation for water storage (10 types of mitigation) against specific mitigation measures (as specified in the Mitigation Measures Template because of their relevance at European level) and the most comparable mitigation measures as listed in Annex 8m of the 2016 WFD Reporting Guidance.

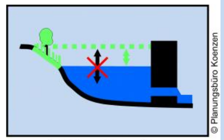
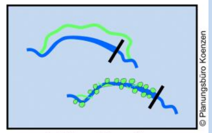
In Table 3 (as well as in other tables and diagrams of this report), the specific mitigation measures are abbreviated. Their full wording is provided in Table 4 thereafter, while the following sections of the report describe them in more detail. Please note that when describing the mitigation measures, we focus on their main mitigation effects. At the same time, we acknowledge that many of the mitigation measures also have side-effects; however, these cannot be treated in detail as this would exceed the scope of this report.

Table 3. Overview of the most widespread key measures to mitigate water storage, linked to the main WFD related ecological impacts and mitigation measures in the 2016 WFD reporting guidance.

Hydromorphological alteration*	**Main ecological impact****	**Mitigation for**	**Mitigation measures options**	**Mitigation measures in 2016 WFD reporting guidance**	**Pictogram**
River continuity for upstream fish migration reduced/disoriented or interrupted	Fish: Populations of migratory fish absent or abundance reduced	Upstream continuity for fish	Ramp Fish pass By-pass channel Catch, transport & release (Fish stocking from hatchery)	Fish ladder* Bypass channels* Removal of structures	 Mitigation for upstream continuity for fish
River continuity for downstream fish migration reduced or interrupted	Fish: Populations of migratory fish absent or abundance reduced	Downstream continuity for fish	Fish-friendly turbines Fish screens By-pass channel Trap, transport & release Fish pass		 Mitigation for downstream continuity for fish
Artificially extreme low flows or extended low flows	Reduced abundance of plant & animal species. Alterations to composition of plant & animal species	Low flow	Provide additional flow River morphology changes	Setting of Ecological flows	 Mitigation for low flow

Hydromorphological alteration*	**Main ecological impact****	**Mitigation for**	**Mitigation measures options**	**Mitigation measures in 2016 WFD reporting guidance**	**Pictogram**
Loss of, or reduction in, flows sufficient to trigger & sustain fish migrations	Migratory fish absent or abundance reduced	Fish flow	Provide fish flow		
Loss, reduction or absence of variable flows sufficient for flushing	Alteration/reduced abundance of fish & invertebrate species	Variable flow	Passive flow variability Active flow variability		
Rapidly changing flows (including hydro peaking)	Reduction in animal & plant species abundance due to stranding & wash out	Rapidly changing flows	Balancing reservoir(s) (internal) Relocate tailrace Reduce rate Modify river morphology Balancing reservoir(s) (external) (Fish stocking)	Operational modification for hydro peaking* (only partly the same) Retention basins	

Hydromorphological alteration*	**Main ecological impact****	**Mitigation for**	**Mitigation measures options**	**Mitigation measures in 2016 WFD reporting guidance**	**Pictogram**
Alteration of general physico-chemical conditions downstream (e.g. temperature, super saturation etc.)	River: Altered composition or growth of macro invertebrate communities and fish or fish mortality Lake: Impact on organic matter, primary production	Physico-chemical alteration	Flexible intake Multiple intakes Manage reservoir level		 Mitigation for physico-chemical alteration
River continuity for sediment disrupted or reduced leading to changes in substrate composition, disruption of morphodynamics in the ponded reaches (artificially stable river banks, disruption of lateral erosion processes)	Reduction in fish & invertebrate abundance & alterations in species composition Thermal changes Alteration or reduction in hyporheic species Alteration of self-purifying properties	Sediment alteration	Mechanical break-up of bed armouring Removal of sediment Re-introduce sediment (intake structures) Re-introduce sediment (reservoirs) Restore lateral erosion processes Introduce mobilising flows (Fish stocking)	Sediment management Removal of structures Restoration of bank structure Ecological flows Dredging minimisation Restoration of modified bed structure	 Mitigation for sediment alteration

Hydromorphological alteration*	Main ecological impact**	Mitigation for	Mitigation measures options	Mitigation measures in 2016 WFD reporting guidance	Pictogram
Artificially extreme <u>changes in lake level</u>, reductions in quality and extent of shallow water & shore zone habitat	Reduction in abundance of plant & animal species. Alteration to species composition Alteration of spawning grounds and nursery areas Hydrological disconnection of wetlands	Lake level alteration	Reduce abstraction Increased inflows Create embayment(s) Manage shore/shallow habitats (renaturalisation) Connectivity to tributaries Artificial floating islands (Fish stocking)	Restoration of bank structure	 Mitigation for lake level alteration
Dewatered shore line and reduced river flow – <u>ponded river</u>	Alterations to plant & animal species composition (e.g. favouring disturbance-tolerant species/still water species) Barrier effect/disoriented fish migration	Ponded rivers (impoundments)	Bypass channel Reduce storage level In-channel habitat improvements Lateral reconnection	Bypass channels Habitat restoration Reconnection of side arms	 Mitigation for ponded rivers (impoundments)

** Including general physico-chemical conditions which are not described by hydromorphological parameters but indirectly caused by the changed hydromorphological conditions.*

*** For certain types of mitigation, there is emphasis on fish as biological quality element according to GEP, especially according to continuity. Nonetheless, all relevant BQEs have to be taken into account for the assessment of ecological potential and evaluation of measure effects.*

Table 4. Full wording and corresponding abbreviation of mitigation measures for the 10 key types of mitigation of impacts from water storage.

Key type of mitigation	**Mitigation measures (abbreviation)**	**Mitigation measures (full wording)**
1. Upstream continuity fish	Ramp	Ramp
	Fish pass	Fish pass (e.g. lift, ladder etc)
	By-pass channel	By-pass channel
	Catch, transport & release	Catch, transport & release of fish
	Stock from hatchery	Stock from hatchery*
2. Downstream continuity fish	Fish-friendly turbines	Fish-friendly turbines
	Fish screens	Fish screens/grids
	By-pass channel	By-pass channel
	Trap, transport & release	Trap, transport & release
	Fish pass	Fish pass (e.g. notch in small intake structure; lift, ladder, ramp, etc)
3. Low flow	Provide additional flow	Provide additional flow to river
	River morphology changes	River morphology changes to make best use of available flow
4. Fish flow	Provide fish flow	Mitigation flows for fish migration
5. Variable flow	Passive flow variability	Passive flow variability (e.g. using natural variability via V-notch weir)
	Active flow variability	Actively delivered flow variability e.g. timed release from dam
6. Rapidly changing flows	Balancing reservoir(s) (external)	Install a balancing reservoir external to the river channel
	Relocate tailrace	Relocate tailrace, including to the sea, a lake, a larger river or a separate channel alongside the original or a recreated river channel
	Reduce rate	Reduce rate at which flow (and hence

Key type of mitigation	Mitigation measures (abbreviation)	Mitigation measures (full wording)
		tailrace recharge) ramps down (including using a bypass valve)
	Modify river morphology	Modify river morphology e.g. by introducing structures to reduce velocity and provide shelter for fish
	Balancing reservoir(s) (internal)	Install a balancing reservoir or series of balancing reservoirs in the river channel
	Fish stocking	Fish stocking*
7. Sediment alteration	Mechanical break-up of bed armouring	Mechanical break-up of bed armouring
	Removal of sediment	Mechanical removal of accumulations of sediment (e.g. to reform pools)
	Re-introduce sediment (intake structures)	Re-introduce sediment downstream of river intake structures (e.g. through sluice gate; passively by weir design; by returning dredging downstream)
	Re-introduce sediment (reservoirs)	Re-introduce sediment downstream of water storage reservoirs (including by actively introducing sediment or passively via a constructed bypass channel)
	Restore lateral erosion processes	Restore lateral erosion processes in river (e.g. by removing engineering) to enhance local sediment supply
	Introduce mobilising flows	Introduce flows sufficient to mobilise sediment (flush fine sediment if colmation and/or mobilise coarse sediment)
	Fish stocking	Fish stocking(*) where interruption of sediment transport means bed characteristics are unsuitable for spawning and/or for juvenile fish
8. Ponded rivers (impoundments)	Bypass channel	Create an artificial bypass channel to provide some flowing water habitat
	Reduce storage level	Reduce storage level (e.g. by raising bed or lowering dam) to increase flowing water habitat

Key type of mitigation	Mitigation measures (abbreviation)	Mitigation measures (full wording)
	In-channel habitat improvements	In-channel habitat improvements
	Lateral reconnection	Lateral reconnection e.g. tributaries, floodplain features such as oxbows
9. Lake level alteration	Reduce abstraction	Limit level variation by reducing abstraction during ecologically sensitive periods
	Increased inflows	Limit level variation by balancing abstraction with increased inflows (e.g. by transfers from another reservoir etc) during ecologically sensitive periods
	Create embayment(s)	Limit level variations in part(s) of the reservoir by creating a separate area (embayment) in which levels are maintained
	Manage shore/shallow habitats	Manage shore/shallow habitats e.g. control erosion, plant overgrowth. Renaturalisation of lake shore or artificial habitats.
	Connectivity to tributaries	Maintain connectivity between reservoir and tributaries for fish movement
	Artificial floating islands	Create artificial floating islands with associated shore/shallow habitats that follow level variations
	Fish stocking	Fish stocking(*) to compensate for lost spawning/rearing habitat
10. Physico-chemical alteration	Flexible intake	Flexible intake (i.e. floating intake able to take water from surface layer of reservoir)
	Multiple intakes	Multiple intakes at different heights that can be alternated as reservoir levels rise and fall
	Manage reservoir level	Manage reservoir levels so that water from surface layers provides the river flow mitigation during ecologically sensitive periods

(*) Fish stocking may be a strategy to compensate various impacts of water storage on fish populations of selected fish species, and/or to optimise fishing. However, as the majority of countries are not considering this as an alternative to reach GEP, this mitigation measure is handled separate from other measures.

5.2 Mitigation of impacts in national lists of mitigation measures

An overview of the most widely used types of mitigation for defining GEP are given in Table 5. More than 50 % of countries are typically requiring at least one measure to mitigate impacts from interrupted upstream and downstream continuity for fish, from low flow, variable flow, fish flow, lake level alteration and rapidly changing flows.

In the same time, many countries are lacking relevant measures to mitigate other significant impacts from water storage. Less than half of the countries require measures for mitigating impacts from sediment alteration, ponded rivers (impoundments) and physico-chemical alterations. For these types of impacts, several countries (8 to 10) responded that they have not identified a need for this type of mitigation (i.e. not identified the impact(s) that this mitigation is designed to address). Several reasons could be related to this response:

1) The country(s) are lacking an appropriate assessment system to capture this type of impact
2) There is no significant impact present in the country(s)
    a) Impact may already be mitigated (to a certain level)
    b) Impact may not be considered significant (due to type of criteria used)
3) Type-specific reasons related to natural ecological situation (e.g. native fish species do not need triggering flow).
4) No management tradition/practice/priorisation to mitigate certain type of impacts, even if similar types of measures are available in national libraries.
5) Unknown situation, legal limitations

Overall, certain types of impacts from water storage may be much more relevant and wide-spread across Europe than the level indicated in the country replies in the table below. The reasons for not identifying the need for certain types of mitigation need to be clarified in the next steps of the GEP intercalibration process.

Table 5. Ranking of key types of mitigation for impacts from water storage for which measures are included in national libraries (based on responses from 23 European countries).

Mitigation for	**Yes**	**No measure in library but impact identified/relevant**	**Not relevant**	**No answer**	**% yes**
Upstream continuity for fish	21	0	2	0	91
Downstream continuity for fish	18	3	2	0	78
Low flow	17	1	5	0	74
Variable flow	15	3	5	0	65
Fish flow	13	1	8	0	57
Lake level alteration	13	2	7	0	57
Rapidly changing flows	12	3	8	0	52

Sediment alteration	11	4	8	0	48
Physico-chemical alteration	8	4	10	0	35
Ponded rivers (impoundments)	8	5	10	0	35

Note: Original response options from the Mitigation Measures Template:

"Yes" = Yes

"No measure in library but impact identified" = No - we have identified the impact(s) that this mitigation is designed to address but not included mitigation in our library of mitigation measures

"Not relevant" = No - we have not identified a need for this mitigation (i.e. not identified the impact(s) that this mitigation is designed to address)

Table 6 presents the individual country replies on whether or not mitigation for the different key types of impact from water storage is included in their national lists (libraries) of mitigation measures for defining GEP.

Possible reasons for not having specific measures in the national library, even though impact is recognised, are:

- Due to management traditions, legal restrictions
- Implementing measures from other countries still pending (R&D not in place); knowledge exchange might be welcome

Table 6. Overview of country replies to question "Is mitigation for this impact included in national list of mitigation measures?"

	1. Upstream continuity fish	2. Downstream continuity fish	3. Low flow	4. Fish flow	5. Variable flow	6. Rapidly changing flows	7. Sediment alteration	8. Ponded rivers (impoundments)	9. Lake level alteration	10. Physico-chemical alteration
Austria – AT	Yes	Yes	Yes	Not relevant	Yes	Yes	Yes	Yes	Yes	Yes
Belgium – BE	------	------	------	------	------	------	------	------	------	------
Bulgaria – BG	Yes	Not relevant	Yes	Yes	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Croatia – HR	------	------	------	------	------	------	------	------	------	------
Cyprus - CY	Not relevant	Not relevant	Yes	Not relevant	Not relevant	Not relevant	No measure in library but impact identified	Not relevant	Not relevant	Not relevant
Czech Republic - CZ	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No measure in library but impact identified
Denmark – DK	Yes	Yes	Yes*	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Estonia - EE	Yes	Yes	Yes	Yes	No measure in library but	Yes	No measure in library but impact	No measure in library but	Yes	No measure in library but

	1. Upstream continuity fish	2. Downstream continuity fish	3. Low flow	4. Fish flow	5. Variable flow	6. Rapidly changing flows	7. Sediment alteration	8. Ponded rivers (impoundments)	9. Lake level alteration	10. Physico-chemical alteration
					impact identified		identified	impact identified		impact identified
Finland – FI	Yes	Yes	Yes	Yes	Yes	Yes	No measure in library but impact identified	Yes	Yes	No measure in library but impact identified
France – FR	Yes	Yes	Yes	Yes (depends on basin)	Yes	Yes	Yes	Yes	Yes	No measure in library but impact identified (depends on structure)
Germany - DE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Greece - EL	------	------	------	------	------	------	------	------	------	------
Hungary - HU	Yes	Yes	Yes	Not relevant	Not relevant	Not relevant**	Not relevant**	Not relevant**	Yes*	Not relevant**
Iceland – IC	------	------	------	------	------	------	------	------	------	------

	1. Upstream continuity fish	2. Downstream continuity fish	3. Low flow	4. Fish flow	5. Variable flow	6. Rapidly changing flows	7. Sediment alteration	8. Ponded rivers (impoundments)	9. Lake level alteration	10. Physico-chemical alteration
Ireland – IE	Yes	Yes	Yes	Yes	Yes	Yes	No measure in library but impact identified	No measure in library but impact identified	Yes	No measure in library but impact identified
Italy – IT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Latvia - LV	------	------	------	------	------	------	------	------	------	------
Lithuania – LT	Yes	Yes	Not relevant	Not relevant	Yes	Not relevant	Not relevant	Not relevant	Yes	Not relevant
Luxemburg – LU	Yes	No measure in library but impact identified	No measure in library but impact identified	No mitigation measure in library but impact identified	No measure in library but impact identified	No measure in library but impact identified	Not relevant	Not relevant	Not relevant	Not relevant
Malta - MT	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Netherlands – NL	Yes	Yes	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Yes	Not relevant	Not relevant
Norway - NO	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No measure in library but impact	Yes	Yes

	1. Upstream continuity fish	2. Downstream continuity fish	3. Low flow	4. Fish flow	5. Variable flow	6. Rapidly changing flows	7. Sediment alteration	8. Ponded rivers (impoundments)	9. Lake level alteration	10. Physico-chemical alteration
								identified		
Poland – PL	------	------	------	------	------	------	------	------	------	------
Portugal – PT	Yes	No measure in library but impact identified	Yes	Yes	Yes	No measure in library but impact identified	Yes	No measure in library but impact identified)	No measure in library but impact identified	Yes
Romania – RO	Yes	Yes	Not relevant	Not relevant	Yes	Yes	Yes	Not relevant	Not relevant	Not relevant
Slovakia – SK	Yes	Yes	Yes	No measure in library	Yes	Not relevant	Yes	No measure in library but impact identified	No measure in library	No measure in library
Slovenia – SI	------	------	------	------	------	------	------	------	------	------
Spain – ES	Yes	Yes	Yes	Yes	Yes	Yes	No measure in library but impact identified	Not relevant	Not relevant	Yes
Sweden – SE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

	1. Upstream continuity fish	2. Downstream continuity fish	3. Low flow	4. Fish flow	5. Variable flow	6. Rapidly changing flows	7. Sediment alteration	8. Ponded rivers (impound ments)	9. Lake level alteration	10. Physico-chemical alteration
UK	Yes	Yes	Yes	Yes	Yes	Not relevant	Yes	Not relevant	Yes	Yes

Notes: (*) Core group's understanding that measure is already in place. (**) Changed from "Yes" to "Not relevant" because there is no detailed measure reported.

Colour code of countries: Green = MMT completed concerning the use of measures in libraries; Yellow = MMT incomplete, some relevant information of template not filled in; Brown = No country response to template.

6 Mitigation for interrupted continuity for fish

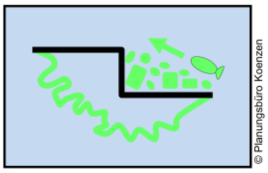
6.1 Description and applicability

The free passage of migratory fish is a key requirement of the WFD, and may be used as an indicator for assessing whether water bodies are meeting good ecological potential or status. River continuum is explicitly mentioned in Annex V of the WFD, and even covers more than fish migration, including other water related biota. WFD Art. 4 and Annex V on ecological potential have a special emphasis on ensuring ecological continuity. This is also a key conclusion from several CIS workshops on HMWBs referred to in chapter **Error! eference source not found.**.

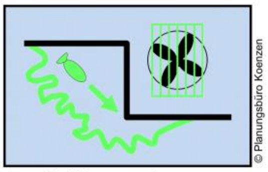
Mitigation measures to ensure fish migration both upstream and downstream for all relevant species, or the ecological function of migratory fish species in all relevant water bodies, is normally to be expected for both GES as well GEP in water bodies affected by water storage, to be in line with the key principles in the Directive. Most countries have self-sustainable measures like various fish pass installations as first option for mitigating barrier effects.

However, impacts on the abundance of relevant species may be mitigated by maintenance measures like trap/transport or fish stocking if there are no other viable options. Several countries like DE and NL have also stated that "permanent fish stocking cannot be used as a measure to mitigate impacts according to WFD. Fish from stocking cannot be considered as an indicator for a certain ecological status or potential. Initial stocking might be an exemption for resettlement of species".

Many of the same mitigation or restoration measures are relevant to other pressures and impacts from man-made obstacles/interruption of fish migration other than water storage impacts such as weirs, road crossings etc. Several detailed manuals, design guidance documents and good practice reports have been produced to mitigate or even restore river continuity and fish migration (e.g. Jungwirth *et al*. 1998, Scottish Executive, 2000; FAO, 2002). There are fewer standards for mitigation of downstream continuity and fish protection so far. However, in France, several recommendations for intake water arrangements linked to downstream migration of fish have been developed (e.g. Porcher & Travade, 2002). Existing mitigation measures refer to the status quo for most countries; further development is necessary and forthcoming.



1. Upstream continuity fish



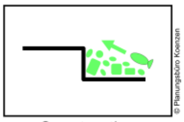
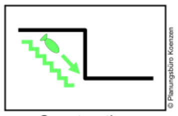
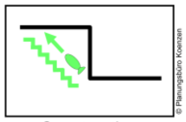
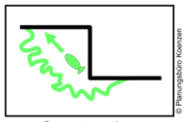
2. Downstream continuity fish

Types of pressures (from water storage)	Dams/turbines Intakes/abstractions Flow depletion
Typical hydromorphological impacts	Continuity reduced or interrupted fish migration due to e.g. barriers, turbine intake or depleted reach
Typical ecological impacts	Populations of migratory fish absent or abundance (species and/or year classes) reduced

REFORM wiki (category, type and link to case studies)	Category 04. Longitudinal connectivity improvement Install fish pass/bypass/side channel for upstream migration
Success criteria for mitigation measures	Increased no of fish passing/surviving and increased/re-established access to spawning and/or rearing habitats leading to increased abundance of fish species/year classes.

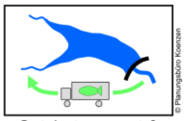
6.1.1 Mitigation measure options or combinations

The following measures (options) for mitigating interrupted fish continuity are identified.

Typical measures (options or combinations for mitigating fish continuity interruption)	
For both upstream and downstream continuity for fish	
Dam removal/modification (NB! Not explicitly mentioned in MMT) If the water use linked to a storage dam is not considered to be of significant importance for society, dam removal or modification is always considered as the ecologically most effective restoration measure.	 Dam removal/ modification
Construction **ramp** A rock-ramp fish way uses normally large rocks and/or timbers to create pools and small falls that mimic natural structures, most appropriate for relatively short barriers. Normally a construction that covers only a part of the river width, with as gentle a slope as possible to ensure that fish can ascend.	 Constructing ramp
Construction of **fish pass** This measure is concerned with a range of in-channel structures, typically referred to as fish passes, and designed to facilitate the upstream and downstream movement of fish (and other aquatic fauna). Fish passes can be applied to water bodies where dams, weirs, or other hydromorphological alteration from water storage prevent or interfere with fish migration. Various types of fish pass constructions may be relevant such as e.g. traditional fish ladders (in concrete), eel ladders and weir passes or baffled passes. Even quite high height differences may be relevant to mitigate by fish passes like fish ladders or lifts.	 Constructing fish pass (downstream)  Constructing fish pass (upstream)
Construction of **by-pass channel** Construction of by-pass channels are particularly well suited to small scale barriers, where the height difference does not lead to an overly long bypass section, and if there is enough space close to the river or outflow from reservoirs. A bypass channel provides opportunity to wholly circumvent the barrier to fish migration and should aim to resemble, in form and function, a side channel or natural tributary of the main river system.	 Constructing by-pass channel

Catch, transport and release*

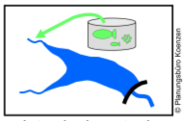
This measure can (to some extent) mitigate interrupted continuity for certain fish species but not all. However, it is not a self-sustainable measure ensuring long term mitigation, and will normally need repeated action. Catch and carry by man or truck transport, are known solutions which are maintenance intensive and are generally considered as having lower effectiveness (both ecological and practical) in all replying countries.



Catch, transport & release

Stock from hatchery*

This measure can (to some extent) mitigate general hydromorphological degradation (more than interrupted continuity) for certain fish species but not all (e.g. not eel). However, it is not a self-sustainable measure and will normally need maintenance/ repeated stocking. Stocking may be of various year and size classes of fish, and even implantment of fish row.



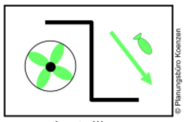
Introducing stock from hatchery

Only for downstream continuity for fish

Installing **fish-friendly turbines** or fish friendly operation

Turbines designed in a way to allow fish to pass through, aiming safe passage for fish or at least reducing the mortality of fish passing. Technology with slower rotating turbine and less blades may improve fish survival without a loss of generation.

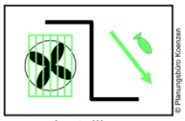
Fish friendly operation/management of power plants is also a known strategy to ensure safe downstream migration of fish species with well known downstream migration strategies (time of year, day/night) like e.g. eels, salmon smolts. This includes both good timing of turbine blade operation and lowering/opening of weirs during migration periods.



Installing fish-friendly turbines

Installing **fish screens**

Mainly physical bar screens/grids, but even electric barrier or strobe light installed as positive exclusion screens to protect migratory fish and then to avoid fish to end up in turbines. Screen design and orientation is crucial and even drop-through screens may be an option. For a safe downstream passage, there is a need to both have an effective screening (proper spacing), diversion and a safe by wash route (e.g. fish way types above as by-pass channel or catch and transport). The screen must have approach velocities (also known as 'escape velocities') and by wash provision. Fish screens may even be relevant in some cases for upstream migration; by avoiding fish to end up in outlet channels/tunnels from turbines.



Installing fish screens

NB! Several of the measures above must be in combination with others. See also the description of flow mitigation measures, as construction of fish ramp, fish pass or by-pass channels will need flow requirements by-passed from the abstraction/dam to function and even attraction flows (fish flow) to ensure fish to enter into fish ways. Fish screens should be combined with a by-pass option to ensure downstream migration or safe transport.

The measures above marked with (*) may not be considered as sustainable measures: 1) Catch, transport and release or 2) Fish stocking – see chapter 12 for further description. However, as the majority of countries are not considering these as an alternative to reach GEP, these mitigation measures are handled separately.

Based on the answers to our MMT, none of the responding countries are considering catch, transport and release as having high ecological effectiveness for mitigating interrupted upsteam or downstream continuity. The figure below also shows that most countries normally are considering by-pass channels, fish passes or ramps as better alternatives to ensure upstream migration of fish. Even though most mitigation measures need some maintenance, the amount of maintenance varies greatly. The emphasis in this report is on self-sustainable measures; in terms of ecological functionality and self-sustainable populations in the long run. In this respect, catch, transport and release is therefore considered as less self-sustainable than other measures, as it is one of the most maintenance-intensive measure in national measure libraries.

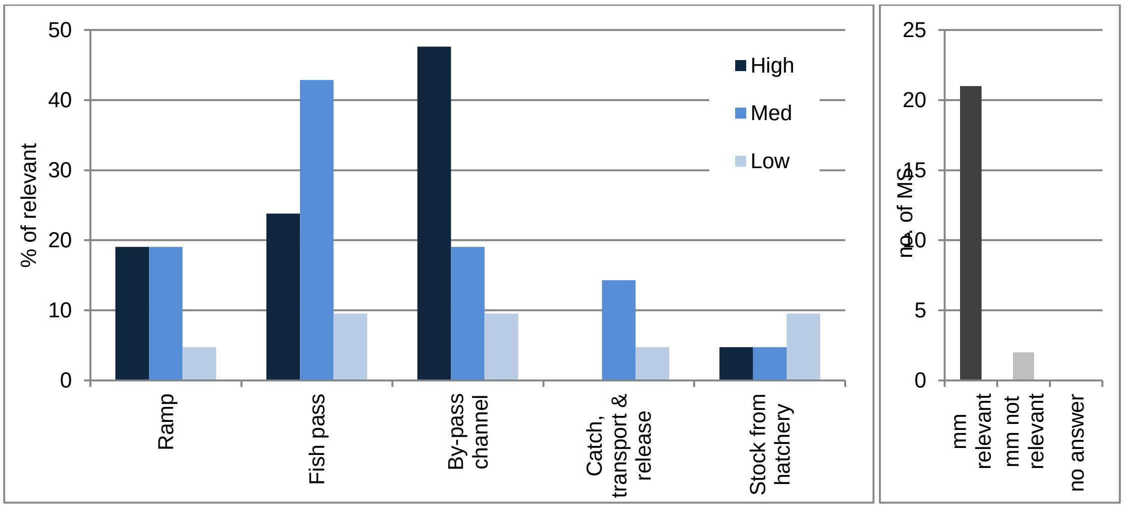


Figure 6. Ecological effectiveness of upstream continuity measures, evaluated by national experts (diagram from the technical annex to this report).

Main conclusions

Relevance of mitigation:

- Continuity for fish is important for all countries, and mitigation of interrupted fish migration is normally expected for GEP (ca. 90% of countries).
- Impact on fish continuity from water storage is the most widespread impact to be mitigated, via measures to ensure upstream continuity in particular.
- Several countries are lacking mitigation measures for downstream continuity, and will need further knowledge exchange or experience.
- When relevant, fish passes are among the most frequently used measures considered as minimum requirements (obligatory if relevant) for GEP in many countries.

Ranking and effectiveness of measures:

- By-pass channels and fish passes have the highest priority in most countries.
- By-pass channels are considered to have relative high ecological and practical effectiveness for upstream migration in most countries, and also for downstream

continuity in many countries. At the same time, proper maintenance is crucial for these types of measures.

- Fish connectivity has to be considered in a holistic manner to ensure sufficient migration success to all relevant habitat types (spawning, rearing etc).
- Longer sequences of fish barriers that need mitigation may be particularly challenging.
- Fish friendly turbines are also considered to have high practical effectiveness for downstream migration in many countries.
- Catch, transport and release or fish stocking have lower priority in all responding countries, and also generally lower effectiveness (both ecological and practical).

Effect on water storage or the wider environment

- Few countries are considering measures to mitigate upstream or downstream interrupted migration of fish to have a high relative effect on water storage.
- Low to no effect on water storage is dominating for these mitigation measures.

Expected frequency for implementation of measures in practice

- Mitigation measures for fish migration, and especially fish passes, ramps or by-pass channels for upstream migration are considered to be implemented nearly always to commonly in many of the countries.
- Mitigation for interrupted downstream migration seems to be implemented to a less frequent extent in HMWBs.
- In some countries, mitigation measures for upstream and downstream migration are always an obligatory measure for GEP (if relevant – e.g. suitable habitat upstream), as they never outrule measures for fish migration in the case of dams.

Main reasons for ruling out measures (NB! Few country replies):

- Technical solutions not possible or disproportionate costs seem to be the dominating reasons for ruling out measures for those countries having filled in this part of the template.
- Not required mitigation is reported for sites with natural fish barriers or, lack of relevant habitats upstream/downstream or uncertainties on the ecological effect from measures on non/short distance migratory fish.
- Effect on water use is not relevant for several countries.
- Most countries do not consider fish stocking as an option for GEP.

7 Mitigation for flow alteration

Quantity and dynamics of flow are crucial elements for the achievement of the WFD environmental objectives.

It is well documented that the hydrological regime plays a primary role in determining physical habitat, which, in turn, determines the biotic composition and supports the productivity and sustainability of aquatic ecosystems. As the structure and functioning of aquatic ecosystems largely depends on the flow regime, significant changes in flow characteristics with regard to magnitude, seasonality, duration, frequency, rate of change, and in intra-annual and inter-annual variability of the flow regime are likely to cause significant impacts on water bodies' ecology (Richter *et al*., 1996; Poff *et al*., 1997; Junk *et al*., 1989; Arthington, 2012).

The WFD explicitly acknowledges the importance of the flow regime for the status of aquatic ecosystems and includes it as one of the key quality elements supporting biological elements in the classification of the ecological status (WFD, Annex V).

When classifying a water body as good ecological status, the conditions of the hydrological regime (quantity and dynamics of flow and the resultant connection to groundwater) have to be consistent with the values specified for the biological quality elements for good status according to the definitions of WFD, Annex V – 1.2.

For deriving good ecological potential which is the alternative environmental objective for artificial and heavily modified water bodies, hydrological as well as morphological conditions have to be taken into account for the consistency with the biological values set according to the normative definitions of the WFD, Annex 5 – 1.2.5.

The evaluation of the first River Basin Management Plans of 2009 made clear that changes to flow regime are one of the main pressure types responsible for failing good ecological status in most European countries and that water resources are often overexploited. Hydropower use, water supply and irrigation were identified to be the main drivers for significant flow alterations.

As a response to these results and recommended by the "Blueprint to safeguard Europe's water resources" (COM 2012), a CIS Guidance on ecological flows (CIS Guidance document no. 31 - Ecological flows in the implementation of the Water Framework Directive, 2015) was developed. It defines e-flow as "a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)".

An appropriate flow regime is also required for HMWBs to achieve good ecological potential. With regard to the definition in WFD Art 2(9), HMWB designation is generally based on the identification of physical alterations which result in a substantial change in character. In CIS Guidance document no. 4 on the "Identification and designation of heavily modifies and artificial water bodies" it was clarified that in cases of temporary or intermittent substantial hydrological changes, the water body is not to be considered substantially changed in character. Nevertheless, it may be that in some limited circumstances substantial hydrological alterations may result in long-term or permanent changes with additional substantial changes in morphology. In such specific cases, the application of the HMWB designation tests may be justified. It was agreed that a slightly different approach could be taken for limited stretches of rivers, e.g. downstream of dams. Under these circumstances, substantial hydrological changes that are accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB.

Based on this, the e-flow Guidance concluded that a careful assessment of the hydrological regime to be delivered should be carried out in the definition of good ecological potential together with the mitigation measures to improve the flow conditions; depending on the nature and severity of morphological alteration, the hydrological regime consistent with GEP may be very close to the ecological flows of natural water bodies.

7.1 Description and applicability

Hydropower generation, water supply and irrigation are the main uses related to water storage which lead to severe flow alterations if not mitigated.

In Figure 4, the typical alterations to the hydrological regime causing ecological impacts on water bodies from water storage (including impoundments) are illustrated. Main flow alterations in rivers are caused by:

- **Water abstraction and transfer to a reservoir** resulting in reduced flow quantity and dynamics downstream of the abstraction point (intake structure)- ”depleted” river stretch.
- **Storing water in a reservoir** often leading to depleted river stretches downstream with regard to quantity and dynamics of flow.
- **Hydro peaking:** Hydropower plants operating for short term regulation of grid or peak load production on demand are causing artificial rapid flow/water level fluctuations downstream of the turbine outlet into the river with extreme low flow and sudden high flow situations. These rapid flow alterations differ significantly from natural flow changes in case of floods.

Taking into account the above mentioned pressures to the flow regime and their impacts on aquatic ecology being the reason for failing the WFD environmental objectives in many European water bodies, we identified the following four main pressure types /flow alterations which need to be mitigated:

- Artificially **extreme low flows or extended low flows** in rivers downstream of water intake structures or downstream of a large dam/reservoir
- **Inadequate fish flows** for long distance migratory fish species to trigger fish migration
- Loss, reduction or absence of **variable flows** (flow dynamics) for flushing
- **Rapidly changing flows** (including effects of hydro peaking)

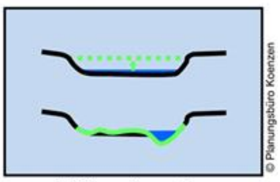
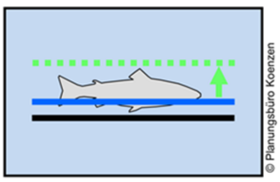
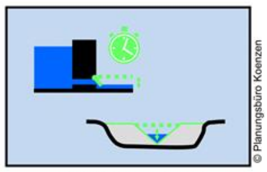
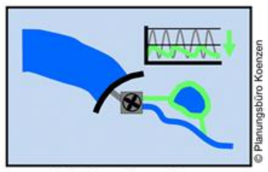
 Mitigation for low flow	 Mitigation for fish flow	 Mitigation for variable flow	 Mitigation for rapidly changing flows

Table 7 summarises the main alterations which are related to each of the four flow pressure types, the typical ecological impacts, the main mitigation measures identified and criteria, by which the success of implemented mitigation measures can be quantified. For more technical information on flow alterations, their ecological effects, measures to reduce the impacts and relevant terms see for example http://reformrivers.eu/.

Table 7. Description of flow pressure types

Types of flow pressures	**Artificially extreme low or extended low flows**	**Inadequate flows for fish migration**	**Loss, reduction or absence of variable flows**	**Rapidly changing flows (incl. hydro peaking)**
Typical alteration to hydromorphological conditions and their functions (hydromorphological impacts)	Reduction in width, depths and velocities; River continuity reduced or interrupted	Loss or reduction in flows sufficient to trigger and sustain fish migration	Loss, reduction or absence of variable flows sufficient for flushing out encroaching vegetation, mobilising and refreshing bed sediment; changes to structure & composition of bed (e.g. armouring, built up of fine sediment)	Rapid changes of magnitude of flow, of water levels and wetted area, of flow velocities leading to surge/downsurge effects; altered sediment regime and habitat quality, changed structure and condition of the riparian zone, reduced bank stability and
Typical ecological impacts	Reduced or interrupted fish migration Reduced abundance of plant & animal species. Alterations to the reference composition of plant & animal species	(long distance) migratory fish absent or abundance reduced	Alteration/reduced abundance of fish & invertebrate species. Alterations in invertebrate composition (favouring disturbance-tolerant species)	Reduction in animal and plant species and biomass in particular due to stranding/dry out and wash out/flushing Altered type-specific riparian vegetation
Main mitigation measures	Provision of additional flow Changes to river morphology	Mitigation flows for fish migration	Ensuring flow variability passively Ensuring flow variability actively	Balance reservoir in stream Balance reservoir external Relocation of tailrace Reducing rate of ramping down

				Modifying river morphology Fish stocking
Success criteria for mitigation	Abundance of (type-specific) plant & animal species increased. Alterations to composition of plant & animal species reduced	Abundance of (long distance) migratory fish increased	Abundance of type-specific fish & invertebrate species increased. Alterations in type-specific invertebrate composition reduced (reduction of dominance of disturbance-tolerant species)	Increase of number and biomass of type-specific animal and plant species Alterations to riparian vegetation reduced

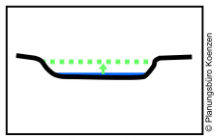
7.1.1 Mitigation measure options or combinations

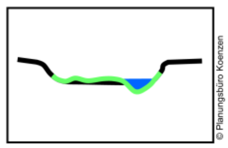
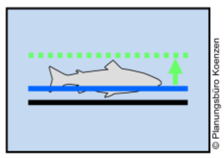
To mitigate extended or even missing low flows, inadequate fish flows, missing/reduced variable flows and rapidly changing flows (mainly due to hydro peaking) the following main measures were identified:

Typical measures for flow mitigation:

<table>
<tr><td colspan="2">Mitigation for low flows

Significant water abstractions without mitigation are usually related to extended low flow situations or even missing flow in the river downstream of the intake structures. A similar negative effect of (seasonally) dried off rivers can be seen in rivers downstream of a dam/reservoir, in which water is stored. Mitigation measures usually are concentrated at reducing the hydrological alteration.</td></tr>
<tr><td>Providing additional flow

Quantity of water flow downstream of intake structure or dam/reservoir, or tailrace is increased by actively delivering additional flow (e.g. by reducing/ limiting the amount of abstracted water, release from dam, ...)</td><td>
Providing additional flow</td></tr>
<tr><td>River morphology changes to make best use of available flow

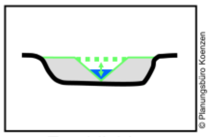
No increase of magnitude of flow, but for example water levels, flow velocities are increased by changing morphological structures of the river downstream of intake structures or dams/reservoir e.g. by narrowing the river bed so that a new «small» river is created within the bed of an originally larger river. It has to be taken into account that this measure might lead to a change of river type (from a larger to a smaller one, also lateral connectivity might be affected. This mitigation measure is sometimes used in combination with the mitigation measures providing additional flow.</td><td>
Optimising river morphology for available flow</td></tr>
<tr><td>Mitigation for fish flows</td><td rowspan="2">
Mitigation fish flow</td></tr>
<tr><td>Mitigation flows for fish migration

Providing an additional fish flow is the only measure to provide an adequate flow which is needed to trigger migration of long distance migratory fish species.</td></tr>
<tr><td colspan="2">Mitigation for variable flows

Significant water abstractions/water storage without mitigation are usually not only related to impacts with regard to low flow situations but also with regard to missing/reduced flow dynamics needed for flushing encroaching vegetation, mobilising and refreshing bed sediment, etc. Mitigation to reduce the hydrological pressure by increasing flow dynamics can only be achieved by providing additional variable flows. This can be done actively or passively.</td></tr>
</table>

Passively providing flow variability

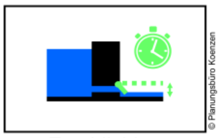
In addition to the low flow components (minimum flow requirements) variable flows are provided to increase flow dynamics passively downstream of intake structures or dams/reservoirs e.g. by using natural variability via V-notch weir.



Establishing variable discharge (passive)

Actively providing flow variability

In addition to the low flow components (minimum flow requirements) variable flows are provided to increase flow dynamics actively downstream of intake structures or dams/reservoirs e.g. via timed release from dam, timed/seasonal limitation of water quantity to be abstracted.



Establishing variable discharge (active)

Mitigation for rapidly changing flows (including effects of hydro peaking)

Short term regulation of grid or peak load production is causing artificial rapid flow changes downstream of the turbine outlet. The flow fluctuations are characterised by a rapid increase of flow when the electricity production starts and a sudden decrease of flow when the production stops. The most important ecological impact of the flow increasing phase (surge) is the wash out effect, by which even fishes are flushed away. The most important impact of the flow decreasing phase (downsurge) is the stranding effect for fish and their larval stages in particular. As the water level and wetted area is very quickly reduced, fish are dying in the bank zone, which are rapidly falling dry.

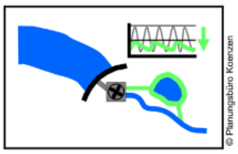
Most relevant for the effect on the aquatic community is the rate of low flow /high flows or the velocity by which the flow decreases in particular. Mitigation measures concentrating on the reduction of the hydrological pressure therefore are focused on decreasing the rate or the velocity of the decreasing phase.

See Bruder et al. (2016) for a conceptual framework to support the ecological evaluation of hydropeaking mitigation measures (based on current mitigation projects in Switzerland and the scientific literature).

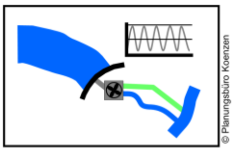
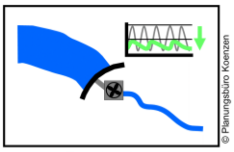
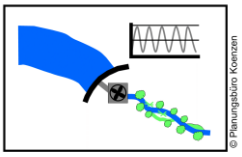
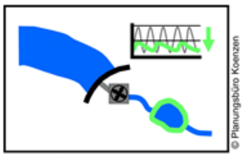
Install a balancing reservoir external to the original river channel

After turbinisation, water is stored before being passed into the river. This can be done for example in an artificial reservoir constructed outside of the river. The turbined water is first discharged into this «external» reservoir from where the water then is continuously released into the river.

The reduction of the rate of flow changes depends on the volume of the reservoir. In case that the volume is large enough, the artificial rapid flow fluctuations can be totally balanced out.

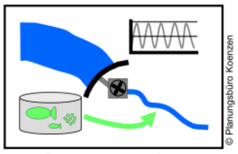


Constructing external balancing reservoir

Relocate tailrace to a sea, lake, a larger river or a separate channel alongside the original river To avoid rapid flow fluctuations, the turbinated water is bypassed into an existing lake, into the sea or into a larger river where the fluctuations are outbalanced by the volume of the receiving water body. It has to be taken into account that with this mitigation measure, hydro peaking impacts are avoided, but there will still remain a river stretch with reduced flow quantity and dynamics downstream of the reservoir. In case of discharge into a larger river possible effects on increased flood risks have also to be considered.	 Relocating tail race
Reduce rate at which flow (and hence tailrace recharge) ramps down (including using a bypass valve) As the water level and wetted area is very quickly reduced by hydro peaking, fish are dying due to stranding. Experiments have shown that reducing the rate /velocity of which flow ramps down is the most crucial and ecologically effective mitigation. This can be achieved e.g. by using a bypass valve, changing the operational mode of the hydropower plant, ...	 Reducing hydropeaking rate
Modify river morphology e.g. by introducing structures to reduce velocity and provide shelter for fish The negative effects of the hydrological alterations due to hydro peaking are usually even higher in case that the morphology of the banks is severely altered and the river channellised. Morphological restoration of the downstream reach could additionally support mitigation effects because of a bigger stream width, the reconnection of side-arms and the creation of pools. Especially pools and side-arms can be used as a refugium for different species during low and/or high flow situations. This mitigation measure usually can not solve the hydro peaking impacts alone but is recommended to be used in combination with other structural or operational measures to raise their positive effect.	 Improving river morphology
Install balancing reservoirs/ series of balancing reservoirs in river channel By constructing an impoundment/chains of impoundment, the spatial extent of rapid flow fluctuations can be reduced by using the balancing capacity of such an «instream reservoir». It has to be taken into account that this mitigation measure also causes ecological impacts as it is associated to a new migration barrier, ponding of a river section, changes in sediment composition/transport, …	 Constructing balancing reservoir(s)

Fish stocking

This measure can (to some extent) compensate negative effects of the artificial rapid flow fluctuations on fish community, but is not a self sustaining measure for ensuring ecosystem functioning in a river. Like morphological improvement this mitigation measure is mainly used in combination with those other hydro peaking measures which are directly reducing the hydrological pressure.



Compensating with fish stocking

For a more detailed description of the pressure-specific hydromorphological alterations, their ecological impacts and mitigation effects see http://wiki.reformrivers.eu

Main conclusions

Relevance of mitigation

- Flow mitigation is definitely considered ecologically important in many countries (21 out of 23 responding countries)
- Relevant aspects are mitigation for low flows, fish flows, variable flows and rapidly changing flows (key types of mitigation) for which 11 main measures in total were identified.
- Most of the countries included flow mitigation measures in their mitigation measures libraries but not always for all of the 11 measures.
- Low flow mitigation is more common than setting measures to ensure fish flows and flow variability or mitigating rapidly changing flows.
- Measures to mitigate rapidly changing flows are mainly addressed in countries with large hydropower schemes.

Flow requirements and relevant aspects

- Flow mitigation is in many countries required for both downstream of an intake structure and downstream of a dam/reservoir including the river upstream of the tailrace.
- Fish is the most relevant BQE taken into account for flow mitigation.
- Most countries apply statistical evaluation of flow value and some countries indicate wetted area as decisive physical factor.
- Mitigation of low flow is sometimes adapted to site characteristics (e.g. considering habitat and/or ecological criteria; etc).
- The maintenance low flow is mainly required all over the year.
- Fish flow mitigation is commonly applied in countries with long distance migrators for both periods of up and downstream migration.
- The required low flow components show large variation but concentrate in the range Q92 to Q97.
- With regard to the magnitude, the mitigation flows for variable flows are usually higher than for low flows.

Ranking and effectiveness of measures for flow mitigation

- Nearly all countries which have indicated to have measures to mitigate flow alterations in their national libraries have a clear picture on the hierarchical ranking of the measures, their (relative) ecological and practical effectiveness and effect on water use. However, the estimations were not done for all of the measures because not all countries apply all of the identified measures on their territory.

- All measures to mitigate flow alterations were qualified to have a high position in ranking as well as concerning ecological and practical effectiveness except fish stocking.
- Fish stocking is usually only an option if there is no other viable option or is used as additional measure supporting other measures due to its (relative) low ecological and practical effectiveness.
- Diverse experiences seem to exist in case of the 6 measures to mitigate rapidly changing flows but for mitigating low flows a clear preference for providing additional flows can be seen due to the high ecological effectiveness compared to morphological optimisation.
- Ecological effectiveness of hydrological mitigation measures may vary according to the synergistic effects with other pressures (e.g. morphological alterations).

Effect on water storage or the wider environment

- Measures related to the provision of additional flows for low flows, fish flows or variable flows and reducing the down ramping rate in case of hydro peaking are usually considered to have a relative high effect on water use compared to other measures.
- Optimising river morphology for low flow mitigation and all other measures to mitigate rapidly changing flows except reducing rate of ramping down are mostly considered to have even no or only low relative effect on water use.

Expected frequency for implementation of measures in practice

- In half of the countries, which have flow mitigation measures included in their national libraries, at least one of the flow measures is estimated to be implemented in practice for HMWBs "nearly always" and nearly 2/3 of the countries when also taking into account a "common" use of the mitigation.
- The frequency of practical implementation varies according to the key types of mitigation: providing additional flow to mitigate low flow is implemented commonly or nearly always in 13 countries while mitigation measures for fish flows, variable flows or rapidly changing flows seem to be more often ruled out or even not included in the mitigation measure library.

Main reasons for ruling out measures

- The reasons for low implementation frequency of flow mitigation measures in general and for ruling out measures need to be better understood in the next phase of the GEP intercalibration process.
- For most of the flow mitigation measures technical infeasibility and disproportionate costs seem to be the most common reasons for being outruled, followed by significant effect on use and effects on wider environment.
- Significant adverse effect on use was mentioned by most of the countries being the main reason for outruling at least one of the flow mitigation measures.
- Significant adverse effect on use is the most common reason for all flow mitigation measures which are related to provision of additional flow in particular.

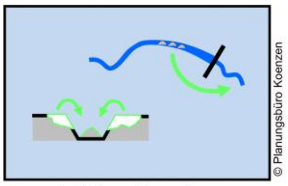
8 Mitigation for sediment alteration

8.1 Description and applicability

Beyond the flow regime, sediment transport plays a fundamental role in determining and maintaining channel morphology and related habitats.

A natural river changes its morphology fundamentally when installing a dam or other barrage across a river section. Permeability is still given for water and mostly for aquatic life by discharge elements and if applicable fish ladders. The extended cross-section upstream of a barrage leads to low current velocities and therefore to profoundly more sedimentation while erosion is minimized. Therefore a barrage often is a barrier for sediment transport. Many reservoirs are affected by massive sedimentation and consequently a loss of storage volume (source REFORM wiki).

Too much sediment in the channel must be managed primarily by reducing their production at source or intercepting it before reaching the channel. The lack of sediment in a river reach is a lot more common problem than excess sediment. The reintroduction of sediments in a reach with sediment deficit can be done by means of upstream dam removal, or by mitigating dam's trapping effects, or by adding sediments directly to the river.

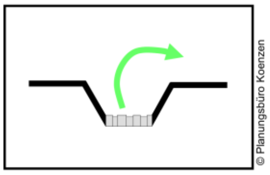
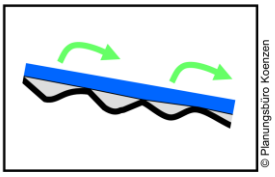
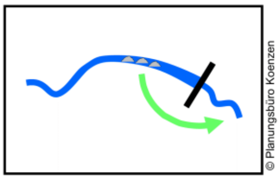


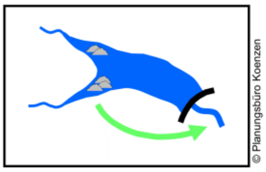
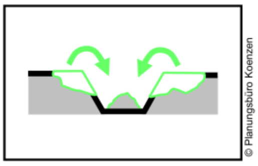
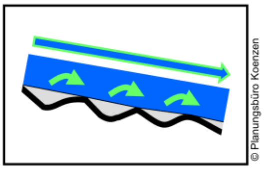
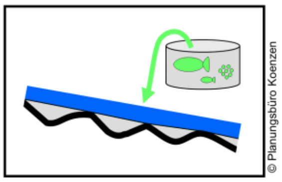
Mitigation for sediment alteration

Types of pressures (from water storage)	Water impoundment River intake structure
Typical hydromorphological impacts	No or reduced river sediment continuity e.g. sediment starvation leading to incised river bed, changes in structure & composition of river bed downstream (e.g. armouring and/or colmation), bank erosion downstream of a structure
Typical ecological impacts	Reduction in fish & invertebrate abundance & alterations in species composition due to poor habitat quality
REFORM wiki (category, type and link to case studies)	Category 02. Sediment flow quantity improvement
Success criteria for mitigation measures	Increased abundance of fish and invertebrate species, increased species richness due to improvements in spawning and/or rearing habitats, diversified river mesohabitats.

8.1.1 Mitigation measure options or combinations

The following measures (options) for mitigating sediment alteration are identified.

Typical measures (options or combinations for mitigating sediment alteration)	
Mechanical break-up of bed armouring Regulated flows can create an armoured substrate because of reduced flushing flows combined with fine sediment loads downstream of dams. However, armoured beds are not necessarily created only due to fine sediment loads. An increase in fine sediment loads with reduced flushing flows leads to bed compaction. Armouring occurs due to the higher frequency of low magnitude events. Because of these constant low flow conditions, bed mobility involves smaller sediment fractions (i.e. sand-silt-clay). Therefore there is a high stability of surface bed material composed of coarser material, with the finer sediment trapped underneath. This measure consists in mechanically breaking up the armoured river bed substrate to re-establish the lost habitats. It should be noted that this measure should be considered together with flow alteration mitigation measures to increase its self-sustainability.	 Removing bed fixation
Removal of sediment Mechanical removal of accumulations of sediment (e.g. to reform pools)	 Removing accumulations of sediment
Re-introduce sediment (intake structures) Re-introduce sediment downstream of river intake structures (e.g. through sluice gate; passively by weir design; by returning dredgings downstream)	 Re-introducing sediment downstream of dam

Re-introduce sediment (reservoirs) Re-introduce sediment downstream of water storage reservoirs (including by actively introducing sediment or passively via a constructed bypass channel)	 Re-introducing sediment downstream of reservoir
Restore lateral erosion processes Restore lateral erosion processes in river (e.g. by removing engineering) to enhance local sediment supply	 Enabling lateral erosion
Introduce mobilising flows Introduce flows sufficient to mobilise sediment (flush fine sediment if colmation and/or mobilise coarse sediment) Mobilising flows are a frequently implemented sediment management strategy and deliver coarse and fine sediments to downstream river sections. At the same time, flushing flows from the bottom outlet of reservoirs often cause high peaks with high loads of fine sediments, which is in many cases a critical alteration for river segments downstream. Ecological optimised flushing operations can minimise such adverse ecological consequences below reservoirs.	 Providing sufficient flows to mobilise sediment
Fish stocking Fish stocking where interruption of sediment transport means bed characteristics are unsuitable for spawning and/or for juvenile fish. This measure can (to some extent) mitigate general hydromorphological degradation (more than sediment alteration) for certain fish species but not all (e.g. not eel).	 Compensating habitat loss with fish stocking

Main conclusions

<u>Relevance of mitigation</u>:

- Mitigation for sediment alteration is not as widely practised as other types of mitigation of impacts from water storage, e.g. for upstream/downstream continuity and flow alterations. Several countries but not all countries have at least one relevant mitigation measure in their libraries.
- 15 out of 23 countries have recognised the impacts from sediment alteration and

11 of them included at least one mitigation measure in their national libraries

Ranking and effectiveness of measures:

- 5 of the 8 countries with ranking give 1st rank to introducing mobilising flows and 4 give 1st rank to restoring lateral erosion processes.
- Measures with high and medium ecological effectiveness are: Restoring lateral erosion (mainly high); Introducing mobilising flows (high/medium); Re-introducing sediment (reservoirs) (medium); Mechanical break-up of bed armouring (high).
- Measures with high and medium practical effectiveness are: Introducing mobilising flows (high); Restoring lateral erosion (high); Re-introducing sediment (reservoirs) (medium).

Effect on water storage or the wider environment

- A high effect on use is not reported by more than one country for any of the mitigation measures for sediment alteration.
- Most countries consider mitigation measures to have no to low effect on water use.
- Only introducing mobilising flows is considered to have a medium effect on use in some countries (6 countries).

Expected frequency for implementation of measures in practice

- Most of the measures related to sediment alteration are not estimated as very common. Only the removal of sediment and reintroducing sediment (downstream of intake structures) are estimated as very common in 1 country. Thus, the measures are mostly very little used but some experience seems to be present in some countries.
- Most frequently used measures are reintroducing sediments (downstream of intake structures) (4 countries).

Main reasons for ruling out measures (NB! Few country replies):

- For the measure introducing mobilising flow, significant effect on use or wider environment is indicated by some countries as common reason for ruling it out (4/1 countries respectively) (but impact on use of occasional flushing flows is likely to be low).
- Technical infeasibility is also reported as common reason for ruling out the measure of removal of sediment (3 countries) and reintroducing sediment (downstream of intake structures) (3 countries).

Other reasons are also likely for not requiring measures for sediment alteration:

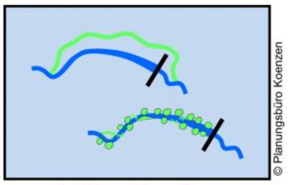
- Impact not detected due to lack of proper (national) assessment system; and/or
- No ecological impact (e.g. because impacted length is too short)

9 Mitigation of ponded rivers (impoundments)

9.1 Description and applicability

Any transverse barrier to the flow in a river impounds water upstream. When this barrier is small (e.g. less than 10 m high) it may be called a weir or small dam. Barriers that are taller than 15 m are all termed dams. All of these barriers are used for retaining water for many purposes and the river is transformed into an impoundment upstream. Adjacent from reservoirs the ponded rivers described here are mostly caused by smaller dams; in many cases, rivers are altered not only by one but several impounded reaches. Natural flow velocity is reduced in these impoundments due to the presence of the dam, resulting in the deposition of transported sediments. In between the impounded reaches there are often free flowing sections in the water bodies with transitional zones between free flowing and ponded.

This type of pressure changes the hydraulic conditions on the impounded river reaches, from lotic to more or less lentic leading to a change of riverine aquatic communities to more stagnant or indifferent ones. A transverse obstacle such as a weir increases water depth and reduces water velocity, and as a result fine sediment is deposited, clogging interstitial habitats. However, when high flows occur, these fine sediments can be mobilised and washed out over these relatively small structures. Small impoundments flood areas that were previously part of the channel margin and floodplain (source: derived from REFORM wiki).



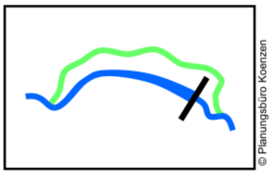
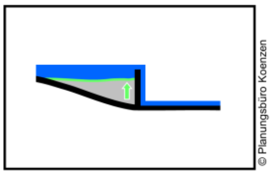
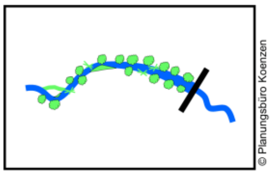
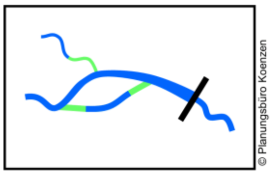
Mitigation for ponded rivers (impoundments)

Types of pressures (from water storage)	Water impoundment
Typical hydromorphological impacts	River flow reduced or ponded Increase of fine substrates (e.g. silt, sand) Hydromorphological processes in the river bed less dynamic Floodplain dynamic reduced
Typical ecological impacts	Alterations to plant and animal species composition e.g. favouring disturbance-tolerant species or still water species, Barrier effect/disoriented fish migration
REFORM wiki (category, type and link to case studies)	Category 04: Morphological alterations
Success criteria for mitigation measures	Increased abundance of fish, invertebrates and aquatic macrophytes, increased species richness due to improvements in spawning, rearing or other habitats,

	especially for rheophilic species. Increased number of growth forms of aquatic macrophytes.

9.1.1 Mitigation measure options or combinations

The following measures (options) for mitigating ponded rivers are identified.

Typical measures (options for mitigating ponded rivers)	
Constructing by-pass channel Constructing by-pass channel to provide some flowing water habitat with type-specific habitat conditions	 Constructing by-pass channel
Reducing storage level Reducing storage level to increase flowing water habitat and reduce impacts of impoundments; e.g. by raising bed or lowering weir/dam	 Reducing storage level
Improving in-channel habitats Improving in-channel habitats e.g. through widening the river bed to develop flat shore zones, developing bank structures or planting/developing typical shore vegetation; especially effective in the transitional zones between the impoundments and free flowing sections upstream with some flowing water	 Improving in-channel habitats
Reconnecting tributaries / floodplain features Reconnecting tributaries or floodplain features e.g. tributaries with important habitats such as spawning grounds, floodplain features such as oxbows or side-channels to improve lateral connection	 Reconnecting tributaries / floodplain features

Main conclusions:

<u>Relevance of mitigation</u>:

- Mitigation for ponded rivers / impoundments is not as widely recognised yet as other types of mitigation of impacts from water storage.

- 13 out of 23 countries have recognised the impacts from impoundments and 8 of them included at least one mitigation measure in their national libraries.
- The relevance of mitigation for ponded rivers / impoundments seems to be underestimated according to the results from the Mitigation Measure Templates.

Ranking and effectiveness of measures:

- Just 4 out of 8 countries ranked their measures for ponded rivers, so no common ranking can be identified.
- Measures with the highest ecological effectiveness are: Reconnecting tributaries / floodplain features; Constructing bypass channel (impounded reaches and barriers) to create flowing water habitat; Reducing storage level to increase flowing water habitat.
- Reducing storage level is the measure with the highest practical effectiveness. For the other measures a high to medium practical effectiveness is mainly considered.

Effect on water storage or the wider environment

- Most countries consider mitigation measures for ponded rivers to have no to medium effect on water use. For in-channel habitat improvements and reconnecting tributaries / floodplain features no effect on the use is dominantly recognised. Constructing by-pass channel is estimated to have a low to medium effect on the use.
- Only reducing storage level is considered to have a low to high effect on the use. This might show the difference between the detailed measure options for reducing storage level. On the one hand there is the option of raising bed level which has in general a lower effect on the use (nevertheless depending on the use). On the other hand the option of lowering the dam has in general a higher effect on the use.
- The technical feasibility of measures for reaching GEP is in general different if a ponded river has navigation as relevant use, especially in the navigation channel.

Expected frequency for implementation of measures in practice

- Improving in-channel habitats and reconnecting tributaries / floodplain features are expected to be the most common measures.
- However, constructing by-pass channel and reducing storage level are considered as uncommonly but likely in a notable proportion of cases from 3 countries.

Main reasons for ruling out measures (NB! Few country replies):

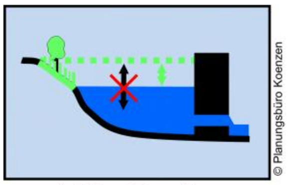
- An identification of main reasons for ruling out measures is – according to very few replies – at the moment not possible.
- Technical solution not possible (e.g. by-pass channel) and significant effect on use (e.g. reduce storage level) are the dominating outruling reasons for most of the measures.

10 Mitigation of lake level alteration

10.1 Description and applicability

Large dams with reservoirs might be built for single or multiple water uses such as hydropower, water supply (e.g. drinking water), flood protection, water regulation (e.g. low water elevation). Depending on the different requirements of these uses the water levels in reservoirs vary over certain periods. For example for flood protection the water level is relatively high during wet periods of high discharge and lower during dry periods. For hydropower use with rapidly changing energy production (hydro peaking), the amount and frequency of the water level fluctuation might be very high in smaller reservoirs.. The largest lake reservoirs in Europe might have gentle fluctuation in lake level due to water use and storage volume, and some store water for several seasons and/or years. The extent of the shore zone may vary and wave erosion may therefore have a significant impact depending on the geomorphological condition in the shore zone.

The fluctuation of the lake level has an influence on the hydromorphological quality of the reservoirs and especially on the habitat quality for biota. A rapid draw down of the lake level can affect e.g. young fish or macroinvertebrates of several species or cause a total dry out of aquatic plants. Flat shore zones are in general the most important habitats affected by lake level alteration in reservoirs. Physico-chemical conditions can also be affected by level fluctuations in a lake/reservoir. Mitigation measures on physico-chemical parameters are included in chapter 11.

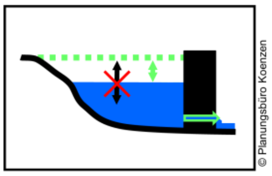
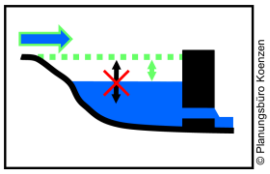
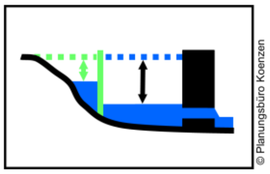
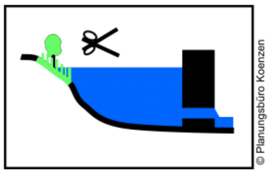
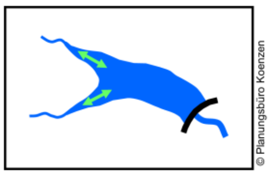


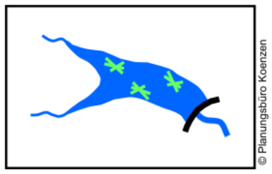
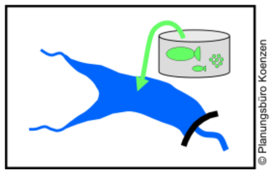
Mitigation for
lake level alteration

Types of pressures (from water storage)	Lake (reservoir) level fluctuation like e.g. draw down with more or less rapidly changing water level in reservoirs
Typical hydromorphological impacts	Artificially extreme changes in lake level leading to reductions in quality and extent of shallow water & shore zone habitat (erosion etc.)
Typical ecological impacts	Reduction in abundance of plant & animal species. Alterations to species composition. Alteration of spawning grounds and nursery areas. Hydrological disconnection of wetlands.
REFORM wiki (category, type and link to case studies)	Lakes are not included in REFORM
Success criteria for mitigation measures	Increased abundance of fish, macroinvertebrates and aquatic macrophytes, increased fish species richness due to improvements in spawning and/or rearing habitats and connectivity to tributaries; increased macrophyte species richness and cover

10.1.1 Mitigation measure options or combinations

The following measures (options) for mitigating lake level alteration are identified.

Typical measures (options for mitigating lake level alteration)	
Limiting level variation – reduced abstraction Limit level variation (amplitude) by reducing abstraction especially during ecologically sensitive periods. Requirement for keeping lake level within a certain height by e.g. spring or mid-summer.	 Limiting level variation – reduced abstraction
Limiting level variation – increased inflows Limit level variation by balancing abstraction with increased inflows, e.g. by transfers from another reservoir etc. especially during ecologically sensitive periods.	 Limiting level variation – increased inflows
Limiting level variation in part(s) of the reservoir Limit level variations in part(s) of the reservoir by creating a separate area (embayment) in which levels are maintained.	 Limiting level variation in part(s) of the reservoir
Managing shore / shallow habitats Implementing managing measures e.g. to control erosion (shore fixation by e.g. vegetation cover) or plant overgrowth. This measure also includes renaturalisation of lake shores and artificial habitats.	 Managing shore / shallow habitats
Maintaining connectivity to tributaries Maintain connectivity between reservoir and tributaries for fish movement e.g. for reaching spawning grounds by fish pass.	 Maintaining connectivity to tributaries

Constructing artificial floating islands Create artificial floating islands with associated shore/shallow habitats or as cover and spawning/rearing habitat for fish/macroinvertebrates/macrophytes that follow level variations e.g. bundles of large woody debris.	 Constructing artificial floating islands
Compensating habitat loss with fish stocking Fish stocking to compensate for lost spawning/rearing habitats if there are no other mitigation options (similar as for other impacts from water storage).	 Compensating habitat loss with fish stocking

Main conclusions:

Relevance of mitigation:

- Mitigation for lake level alteration is recognised as a relevant type of mitigation of impacts from water storage. Many countries but not all countries have relevant mitigation measures in their libraries.
- 15 out of 23 countries have recognised the impacts from lake level alteration.
- 13 of them included at least one mitigation measure in their national libraries.

Ranking and effectiveness of measures:

- Just 5 out of 13 countries have ranked their measures for lake level alteration, so no common ranking can be identified.
- Measures with the highest ecological effectiveness are (mainly high to medium): Reduce abstraction, increased inflows and connectivity to tributaries while reducing abstraction seems to have the highest ecological effectiveness. The other measures are considered as medium (create embayments) or medium to low effectiveness (the others).
- Measures with the highest practical effectiveness are: Reduce abstraction, create embayment(s) and connectivity to tributaries. The other measures were identified as medium to low (e.g. increased inflows) or low practical effectiveness (fish stocking).
- For monitoring effects of measures according to lake level changes it is necessary to apply a limnological approach.

Effect on water storage or the wider environment

- Most relevant measures seem not to have a significant adverse effect on water storage or wider environment.
- All countries consider the measures to create embayment(s), manage shore/shallow habitats, connectivity to tributaries, artificial floating islands, fish stocking to have no to low effect on water use.
- Reduce abstraction or increased inflows are considered as having high to low effect on use. This also depends on seasonality. Reducing abstraction can be especially difficult to achieve during summer e.g. according to irrigation.

Expected frequency for implementation of measures in practice

- The expected frequency according to most of the measures varies between countries.
- Most countries considered the majority of the measures as uncommonly or very rarely used. However, reducing abstraction, connectivity to tributaries, creating embayment(s) and fish stocking are considered to be implemented more commonly or nearly always at least by several countries.
- Increased inflows and artificial floating islands are estimated as uncommonly or very rarely implemented by all countries.

Main reasons for ruling out measures (NB! Few country replies):

- An identification of main reasons for outruling measures is – according to very few replies – at the moment not possible. Nevertheless, significant adverse effect on use / wider environment was considered from all countries for reducing abstraction.
- Technical solution not possible, disproportionately costly and impact not present

are the dominating reasons for ruling out measures according to the other measures reported for this type of mitigation.

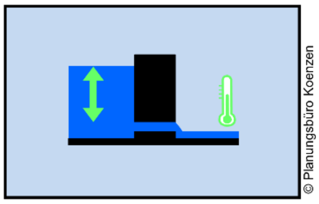
11 Mitigation for physico-chemical alteration

11.1 Description and applicability

Typical hydromorphological alteration: Water storage and river regulation through hydropower plants may alter physical and/or chemical conditions downstream the water storage, with changes such as water temperature, supersaturation of nitrogen and altered patterns of ice formation in winter (mainly in alpine areas or in Northern Europe). Typically for deep reservoirs (not ponded rivers) the water temperature often increases in winter and decreases in summer due to deep-water intake in reservoirs, with decreased water-air contact of water.

Abstraction and altered mix of water with other origin may also change water quality or supersaturation (of nitrogen), but these impacts (except for temperature alteration) have not been explicitly addressed in our MMT.

Ecological impacts: Altered composition or growth of macroinvertebrate communities, fish and aquatic flora or increased fish mortality due to e.g. increased smolt age or diving disease due to oversaturation. Altered water temperature may lead to changed energetics /metabolism due to increased winter temperature (increased metabolism after regulation) and decreased metabolism and growth during summer. The time for hatching (fish and invertebrates emerging from eggs) may also be significantly altered, increased larvae stage and suboptimal feeding conditions. Reduced ice cover, altered water quality, temperature and oversaturation may also lead to behavioral impacts for fish. Reduced ice cover also leads to changed light penetration with impact on aquatic vegetation.



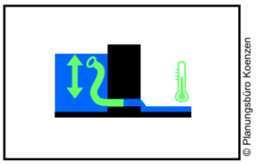
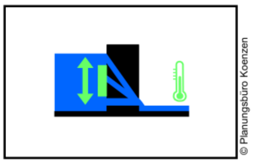
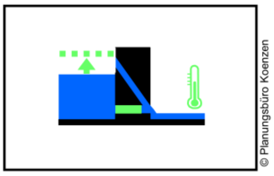
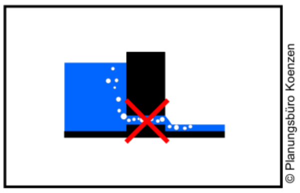
Mitigation for physico-chemical alteration

Types of pressures (from water storage)	Dams/regulated lake/reservoir Abstractions Re discharge of flow
Typical hydromorphological impacts	Alteration of general physico-chemical conditions downstream of water storage due to e.g. transaction of water and/or deep water intake in reservoir leading to altered water temperature or quality and ice conditions in alpine rivers.
Typical ecological impacts	Altered composition or growth of biological quality elements and survival/growth rate of fish in particular.
REFORM wiki (category, type and link to case studies)	Category 01. Water flow quantity improvement Water diversion and transfer
Success criteria for mitigation measures	Mimicking more natural physico-chemical conditions like natural values and differences in seasonal water temperature (naturalise temperature regime), as

	increased growth and survival of fish and macroinvertebrates as well as more natural composition of biological quality elements.

11.2 Mitigation measure options or combinations

To mitigate this impact as described above, which means to reduce negative effects of physical or chemical alterations due to water storage, the following main mitigation measures (options) were identified:

Mitigation for physico-chemical alteration – e.g. water temperature	
Installing flexible intake Flexible intake arrangements in storage reservoirs enable intake of controlled water at different depths for mimicking a more natural and hence less physical or chemical alteration. E.g. intake of (sub-)surface water, which normally is more in contact with air, and therefore of less altered temperature than deeper reservoir water.	 Installing flexible intake
Multiple intakes at different heights in reservoir dams Multiple intake arrangements in storage reservoirs enable controlled intake of water at different depths for mimicking a more natural and hence less physical or chemical alteration, even though not as flexible as for flexible intakes.	 Multiple intakes at different heights in reservoir dam
Managing lake/reservoir level Managing reservoirs levels by operational planning in particular related to water temperature at different times of the year. In ecological sensitive periods (e.g. during spawning / larval stage of certain fish species) surface water with less altered temperature can be delivered to downstream reaches to reduce e.g. temperature alteration.	 Managing reservoir level
Mitigating oversaturation (NB! Not explicitly mentioned in MMT) Deep water intake and/or avoid air mixing into intake before water is under pressure to avoid/reduce lethal level of oversaturation.	 Mitigating oversaturation

Main conclusions:

Relevance of mitigation:

- Physico-chemical alteration from water storage such as altered water temperature downstream re-discharge from hydropower station is so far not very common.
- Compared to other types of impacts, physico-chemical alterations are among the less recognised impacts from water storage use and relatively few countries have mitigation measures in their libraries.
- 12 out of 23 countries have recognised ecological impacts from temperature (physico-chemical alteration), and 8 of them have included at least one relevant mitigation measure in their national libraries. Four countries have recognised the impact but are presently lacking relevant measures.
- Mitigating water temperature alteration from water storage has been main focus in the MMT, but impacts from oversaturation or altered water quality are also related to similar type of mitigation measures

Ranking and effectiveness of measures

- Flexible or multiple intakes are considered as having the highest ecological effectiveness.
- There is too little experience to get a clear ranking of alternative measures.

Effect on water storage or wider environment:

- No country considers relevant measures to have a high effect on water use.
- Two out of five countries consider reservoir level managing to have medium effect, while the rest of countries or measures are considered to have no to low effect on water use.

Expected frequency for implementation of measures in practice:

- There is little experience with this type of mitigation measures or impact in most countries, but three countries consider measures to mitigate temperature alteration nearly always to be implemented in relevant HMWBs.
- Most countries consider this measure not to be commonly implemented, but several answered “don’t know – too early to say”

Reason for ruling out measures (NB! Few country replies!):

- Significant effects on water storage or disproportionate costs seem to be dominating reasons for ruling out these mitigation measures.

12 Sustainable vs. non-sustainable mitigation solutions

In the WFD classification system, the definition of "ecological status or potential" is an expression of the quality of structure and functioning of aquatic ecosystems, monitored as presence of selected species. This should normally be ensured by permanent measures (sustainable measures), if the ecological status/potential is already good. In river basins where migratory fish species are present, the long term preservation of sustainable populations of fish and other communities relies on effective and long-term meaningful solutions for longitudinal continuity. The non-sustainability of mitigation measures refers to the lack of self-sustainability in terms of communities, not the economic sustainability of measures.

Based on the replies from the national water managers responsible for national measure libraries, the majority of countries reported the following measures as not fulfilling long-term meaningful and functional solutions: namely fish stocking or catch, transport and release (see Table below). For both types of measures, the mitigation is fully dependent on maintenance and repeated action; if not, the ecological effect stops.

Fish stocking is considered in some countries as an option for multiple impacts from water storage like e.g. interrupted continuity, sediment, flow or lake level alteration. However, stocking is normally not implemented for non-commercial fish species, except possibly for the initial stage of restoration. In addition, for most countries, stocking is not considered as a relevant measure for GEP (other types of mitigation should normally be implemented), but still a measure that is considered as better than doing nothing (e.g. for moderate ecological potential). Catch, transport and release is mainly relevant for mitigating interrupted fish continuity, which requires much more man-work than normal maintenance for other fish ways solutions (see chapter 6.1 for more details).

In several countries, fish stocking is an obligatory compensatory measure made pursuant by decision in water courts or part of old terms of a license, e.g. for water abstraction initiated before the adoption of the WFD.

Table 8. Use of fish stocking as mitigation measure in HMWBs impacted by water storage.

		Implementation frequency			
Fish stocking river/lakes		**Nearly always**	**More common than not**	**Uncommonly /rarely**	**Not a relevant measure**
Fish stocking - continuity	**Nb**	**1**	**2**	**3**	**8**
	Countries	FI	NO, CZ	IE, EE, IT	AT, CY, DE, ES, FR, PT, SK, SE
Fish stocking - rapidly changing flows	**Nb**	**1**	**3**	**1**	**7**
	Countries	FI	NO, IE, CZ	EE	AT, DE, UK, PT, SE, CY, FR
Fish stocking – sediment alteration	**Nb**	**0**	**2**	**2**	**7**
	Countries		NO, CZ	UK, IT	AT, DE, PT, FI, SE, CY, FR

Fish stocking - lake level alteration	**Nb**	**1**	**2**	**1**	**8**
	Countries	FI	IE, NO	UK	AT, CY, DE, ES, FR, PT, SK, SE

Main conclusions:

- Fish stocking may be a solution to compensate various impacts of water storage on fish populations (on selected fish species), and/or to optimize fishing.
- However, as the majority of countries are not considering fish stocking as an alternative to reach GEP, this mitigation measure is handled separately (and not as a valid alternative as mitigation measure for GEP).
- Transport options for fish that need maintenance, do not normally provide a long-term ecologically meaningful and aquatic functional solution in line with the WFD.

13 Scale of impacts typically mitigated

There seems to be a variation in the average minimum extent of impact (e.g. river length of an impacted river) typically addressed for mitigating different significant hydromorphological alterations across Europe.

Overall, several countries (e.g. IT, DE, FR; see Table 9 for full country details) seem not to have assigned a typical minimum length to the impacted reach but determine it on the basis of the combination of pressures and river behaviour, which takes into account the size of water bodies. These countries probably have a comparable scale of impact if all relevant impacts on water body level are taken into account.

The magnitude of the impacts can depend on the river sensitivity and this in turn is linked to the river morphology, if the river is high or low energy, the type of pressures in and off site and its evolutionary trajectory.

For the mitigation of impacts related to continuity and flow, most countries with a relevant quantification refer to the use of a minimum scale of impact between 0.5 and 3 km. Only few countries seem to address impacts to be mitigated for stretches smaller than 0.5 km. In the same time, certain countries such as FI use a large typical scale of impact, higher than 10 km, for which mitigation is considered.

Table 9. Typical length (minimum scale of impact) for which mitigation would be considered in water bodies

	River length (km)							
Mitigation measure	**<0.1**	**0.1-0.5**	**0.5-1**	**1-3**	**3-5**	**5-10**	**>10**	**Not quantified***
Upstream continuity for fish			DK, CZ NO, SE, AT	UK	EE		FI, RO	BG, DE, IE, IT, FR, PT, SK, ES, LT, NL
Low flow			DK, NO, SE, AT	UK	EE		FI	DE, IE, IT, FR, NL, ES, PT
Downstream continuity for fish			DK, NO, SE	UK	EE		FI, RO	ES, AT, DE, IE, IT, FR, NL
Variable flow			SE	AT, UK			FI	DE, IE, IT, FR, NO, RO, ES, LT, PT
Fish flow	EE		SE, NO	AT, UK			FI	BG, DE, IE, IT, FR, PT
Rapidly changing flows	EE		NO, SE	AT			FI	DE, IE, IT, FR, RO, ES

Sediment alteration	UK	CZ	SE	AT				DE, IT, FR, NL, NO, PT, RO
Ponded rivers (impoundments)			SE	AT	NO		FI	DE, IT, FR, NL
Physico-chemical alteration			SE	UK, AT		NO		DE, IT, PT, ES

(*) For some countries it varies/is site specific.

Typical length for river HMWBs varies by a factor of approximately 30 between WFD implementing countries, based on reporting of river HMWBs in the first RBMPs. When comparing the typical minimum scale of impact typically addressed with the average size of HMWBs in the different countries (see Table 10 below), we can see certain correlations. FI, RO and NL which use a minimum scale of impact > 10 km for one or more types of impact are among the countries with larger HMWBs in average (> 20 km of length). Other countries such as AT, DK and SE which tend to typically address impacts for mitigation at a lower minimum scale between 0.1 and 3 km also have on average HMWBs of smaller size (equal or < 5 km).

Table 10. Mean length of river HMWBs by country (sorted from largest to smallest average length).

Country	**Numbers (Nb)**	**Total length in km (SizeL)**	**Average length (Km)**
LV	27	907,9	33,63
FI	79	2538,8	32,14
BG	179	5415,7	30,26
FR	355	10594,3	29,84
PL	1504	42957,5	28,56
RO	500	13587,5	27,18
HU	350	8123,1	23,21
SI	7	151,9	21,7
LT	103	2149	20,86
NL	238	4585,5	19,27
CZ	175	3132,9	17,9
ES	737	11116,5	15,08

EE	152	2250,5	14,81
SK	53	728,6	13,75
PT	102	1365,8	13,39
BE	162	2078,4	12,83
UK	1935	23090,7	11,93
DE	3531	39598,8	11,21
IT	734	6802,5	9,27
CY	49	434,2	8,86
EL	160	1350	8,44
AT	566	3117	5,51
SE	368	1984,5	5,39
IE	1	1,5	1,5
DK	1140	904,8	0,79
HR	0		0
LU	11	0	0
MT	0		0

Note 1: Calculation of average length of HMWBs based on data from http://discomap.eea.europa.eu/report/wfd/SWB_SIZE_AVERAGE

These data were reported as part of the 1st River Basin Management Plans.

Note 2: In some Member States, reservoirs are included in river HMWBs.

For the mitigation of impacts related to lake level change, 5 out of 9 countries with a relevant quantification use a minimum scale of impact (change in water level) of ca. 1m. See Table 11 for full country details.

Table 11. Typical scale of impact (change in water level) for which mitigation would be considered in water bodies (lakes/reservoirs).

	Lake level change (in meter)			
Mitigation measure	**+/- <1 m**	**+/- 1-3 m**	**+/- >3 m**	**Not quantified**
Mitigation lake level	EE, FI, LT, SE, UK	AT, IE, CZ	IT, NO	FR, DE, HU

Main conclusions

- There seems to be no harmonised approach on the minimum scale of river length or lake level change typically addressed to mitigate impacts from water storage.
- Typical length for mitigating impacts like fish flow varies with a factor of >100 and for several other impacts by a factor of 10 to more than 20 between countries.
- However, a high number of countries have not indicated any typical length or lake level for mitigation of key impacts.
- The lack of a clear limit for typical scale of impact to be mitigated concluded from our country information exchange, might lead to a lack of harmonisation for GEP-requirements. Therefore, clearer CIS guidance/intercalibration on scaling issues seems necessary.
- The scale of impact is in general difficult to compare between MS. The main reasons might be especially differences in water body length, level of impairment and selection/effects of measures as well as lack of practical experience.
- To get better understanding of possible site-specific reasons for the large variation in scale (size/significance of impacts) to be mitigated, a more in-depth comparison of case studies might be needed as the next step in intercalibration of GEP.

14 Significant adverse effect on water use and wider environment

14.1 Significant adverse effect upon storage for hydropower

Recalling key conclusions from earlier CIS workshops (before 2012)

The following summarises key conclusions and recommendations from previous CIS workshops on HMWBs, hydropower and the WFD on the assessment of significant adverse effects on storage which serves hydropower production.

In the CIS workshop on HMWBs in 2009, it was concluded that:

- The reasons and criteria for judgements on significance should be made clear.
- The workshop recommended that it is good practice to be clear on what is taken into account when making judgement.
- Several factors appear to be possible considerations in determining if an impact on hydropower generation is significant:
    - Proportion of scheme's total output
    - Proportion of annual variation in scheme's total output
    - Proportion of renewable energy targets
    - Cumulative impact on renewable energy targets
    - Scale of benefit to the water environment

Significant effects can be determined at the level of water body, group of water bodies, a region, a RBD or at national scale. The starting point will usually be the assessment of local effects (WFD CIS 2003, CIS Guidance no.4).

In the CIS workshop on water management, hydropower and the WFD in 2011, European countries were asked whether they have agreed national or local criteria for determining what effect on hydropower is acceptable. The survey in 2011 showed that 10 countries had defined criteria for determining significant adverse effects on hydropower, but in an equal number of countries, no such criteria had been determined (see table below).

Table 12. European countries replies on significant adverse effects on hydropower for the CIS workshop on Hydropower and the WFD in 2011

	Yes	No
Agreed national or local criteria for determining what impact on hydropower generation is acceptable (i.e. not a significant adverse effect)	(AT), FR, IT, LV, LT, NL, RO, CH, IS, ES	BG, DE, FI, LU, NO, PT, SE, UK, CZ, SI

Note: No answer by BE, HU and PL.

Country replies in the GEP Mitigation Measures Templates (2014-2015)

In total, 17 countries provided information on the way of determining significant adverse effect of mitigation on hydropower. Table 13 summarises country replies on the presence (or absence) of national framework criteria for deciding upon "significant adverse effect on hydropower" (WFD Art 4(3)) as a basis for ruling out certain mitigation measures:

- 5 out of 17 countries have national framework criteria for determining significant effect of mitigation on hydropower. In NO, national assessment at policy level has been developed, that can apply as a guide on how to prioritise flow mitigation measures in catchments/river segments with highest potential benefits.

- 12 out of 17 countries have no national framework criteria and in 5 of these countries, the assessment of significant effect on hydropower is done on case-by-case basis or expert evaluation.
- The framework criteria look at the national level in 5 countries and at the scheme level in 3 countries.
- In 3 countries, the criteria look at total production and in 2 countries at both total production and regulatory power. In SE, in specific, there are different criteria for significant effect on use for production, balancing and frequency regulatory power.
- In 4 countries, the criteria relate to a percentage (%) against a fixed baseline. In SE, a fixed baseline is used but could be changed in an adaptive management. In 2 countries, the criteria do not relate to a percentage (%) but relate to specific case-by-case conditions. In FI, although a case specific assessment is practised, it was indicated that criteria on significant effect on use are often between 1-5 %.

Table 13. Country replies on the presence (or absence) of national framework criteria for deciding upon "significant adverse effect on hydropower" (Art 4.3) (Mitigation Measures Template on storage)

Do you have national framework criteria for deciding "significant effect on storage hydropower"?	Yes	NO, RO, UK, SE, (AT)
	No	DK, DE, LT, SK, IE, FI, PT, EE, ES, CY, FR, HU, CZ
	No/Case-by-case	DE, DK, FI, EE, ES, PT
	No/Expert evaluation	-
	No/Local criteria	IE
	No/No hydropower	CY
Does the framework look at total production, just regulatory power or both?	Total production	NO, RO, UK
	Total production & regulatory power	SE, , AT
What level does the framework look at?	National level	LT, NO, UK, SE, , AT
	Scheme level	RO, IE, AT

What are the criteria on significant effect on use related to?	Percentage (%)	RO, UK, SE, AT
	Case by case	NO, AT
If % criteria, are they against a fixed baseline or a moving baseline?	Fixed baseline	RO, UK, SE, AT
	Moving baseline	-
Has this been established through a public consultation process?	Yes	RO, UK, AT
	No	NO (ongoing as part of RBMP consultation), SE,

Notes: No reply from BE, BG, HR, EL, IC, IT, LV, LU, MT, NL, PL, SI.

FR has no national framework criteria for deciding "significant effect on storage hydropower", but has national legislation and a water regulation by structure.

Countries were also asked to indicate what they expect to be the most common reason for ruling out different mitigation measure options. One of the possible reasons for ruling out measures was "a significant adverse effect on water storage". Overall, only a few countries replied with details to this question. The key measure types for which "a significant adverse effect on water storage" is more frequently used as a reason for ruling out mitigation measures are:

- Measures for mitigation of low flow (especially providing additional flow to river) (7 out of 10 countries)
- Mitigation flows for fish migration (5 out of 7 countries)
- Measures for mitigation of variable flows (especially actively delivered flow variability, e.g. timed release from dam) (6 out of 8 countries)
- Measures for mitigation of lake level change (especially limit level variation by reducing abstraction during ecologically sensitive periods) (4 out of 5 countries)
- Measures for mitigation of sediment alteration (especially introduction of mobilizing flows) (4 out of 7 countries).

For measures related to upstream and downstream continuity for fish, "a significant adverse effect on water storage" is rarely used as a reason for ruling out measures.

Outuruling of a technical mitigation measure due to significant adverse effects on use may also include cases whereby safety is endangered (this may also be the case for mitigation measures considered for HMWBs designated due to their use for flood protection).

Based on CIS information exchange activities (workshops or templates) since 2011, the following countries have indicated having criteria (national or local) for determining significant adverse effects of mitigation on hydropower.

Source	Yes (national or local criteria)	No	No information (no response)
2011 CIS Workshop on Hydropower and the WFD	(AT), FR, IT, LV, LT, NL, RO, ES, CH, IS	BG, DE, FI, LU, NO, PT, SE, UK, CZ, SI	BE, HU, PL
2016 Mitigation Measures Template	AT, NO, RO, SE, UK (national) IE (local)	DK, DE, LT, SK, IE, FI, PT, EE, ES, CY, FR, LT, HU, CZ	BE, BG, HR, EL, HU, IC, IT, LV, LU, MT, NL, PL, SI

The box below gives a summary of the Swedish national strategy for determining significant adverse effects of mitigation on hydropower.

Box 1. Examples of national criteria/strategies for determining significant adverse effects of mitigation on hydropower

The Swedish national strategy for measures on Hydropower

Sweden has about 4000 water bodies in rivers and about 2000 lakes which are regulated for hydropower production. The number of hydropower plants exceeds 2100 but there are additional 1000 dams used for water regulation. 208 of the hydropower plants are larger than 10 MW and produce 93 % of the total hydropower production and almost all regulating power.

During the work on the implementation of WFD, it became obvious that measures needed to reach GES would have significant negative effects on the production of hydropower in Sweden. Even if Sweden presently has an excess production of electricity, the need of hydropower as a source of regulatory power to balance the rapidly increasing share of wind power, is of major importance. The possibility to produce regulatory power in different time scales varies however among the hydropower plants and the different catchments. It was obvious that a national prioritization was needed to resolve the balancing between reaching WFD goals and goals regarding climate change and renewable energy production. A joint project was set up by the Swedish Agency for Marine and Water Management, SWAM, and the Swedish Energy Agency. Attached to this project was also a reference group with representatives from the hydropower sector, different NGO's, regional administrations and other national agencies.

In this strategy[1)], all catchments in Sweden were assessed regarding energy and environmental values. The approach was a multi criteria analysis in which the energy and environmental values were composed of many different parameters which were combined by using weights. The energy values were assessed on individual hydropower plants level and combined into one value per catchment. The environmental values were evaluated by a large amount of parameters such as present ecological status, number of localities of species of the Habitats Directive, amount of protected water, number of river length or lakes in high status, amount of lakes and rivers with functional riparian buffer zone etc. All parameters were normalized and combined using weights. In the end, each catchment was characterized with a value between 0 and 1.0 regarding energy value and conservational value.

In a second step, all catchments were clustered into seven groups using K-means cluster analysis based on all parameters. Each cluster group was provided with a strategy regarding environmental measures, but also measures in respect to additional hydropower production and water regulation. In the majority of the catchments, the suggested focus was on reaching good ecological status, whereas in ca. 10 catchments, the regulatory power of the hydropower should be maintained or even increased.

In addition, a calculation of hydropower production loss was carried out using the above strategy. The result suggested that 1.5 TWh out of 65 TWh is needed to implement environmental flows to reach GES and also water in 1600 fish passages. The strategy also suggested that environmental measures in 120 hydropower plants above 10 MW would be limited due the very high value in the energy system. In these water bodies, the use of HMWBs or even less stringent requirement from GEP might be needed [2)]. If this strategy is implemented, there would be limited adverse effect on total production of regulatory power in Sweden. Some of the production loss might be compensated by efficient increase in large hydropower plants in HMWB.

The national strategy has been well accepted by the hydropower sector but also NGOs. After the National strategy was published, high level discussions have been carried out with the hydropower sector and NGOs by the two agencies. These discussions provided a proposal to the Government to finance an implementation of the strategy by using an environmental fund totalling 1,3 billion € during the next 20 years. The fund was supposed to be financed by all hydropower plants according to a fixed cost per kWh and, by a smaller share, by the government funds. In the recent all-party agreement regarding the future energy system from June 10th 2016, the environmental fund was accepted with some minor changes.

Sources: 1) National strategy (In Swedish) https://www.havochvatten.se/hav/samordning--fakta/samverkansomraden/energi/nationell-strategi-for-vattenkraft-och-vattenmiljo.html

2) National guide for HMWB due to hydropower (In Swedish): https://www.havochvatten.se/hav/uppdrag--kontakt/publikationer/publikationer/2016-06-03-vagledning-for-kraftigt-modifierat-vatten.html

14.2 Significant adverse effect upon storage for uses other than hydropower

Storage for water supply

In total, 17 countries provided information on the way of determining significant adverse effect of mitigation on water supply in the MMT. Table 14 summarises country replies on the presence (or absence) of national framework criteria for deciding upon "significant adverse effect on water supply" (Art 4.3) as a basis for ruling out certain mitigation measures:

- Only 2 out of 17 countries have national framework criteria for determining significant effect of mitigation on water supply.
- 15 out of 17 countries have no national framework criteria and in 4 of these countries, the assessment of significant effect on water supply is done on case-by-case basis. In 5 countries, significant effect of mitigation on water supply is considered not relevant or to a limited extent, either because surface water is not used (extensively) for water supply or because water supply is not considered as a use for HMWB designation.
- 1 country (UK) indicates demand supply balance as criteria for determining significant effect of mitigation on storage for water supply (creating a negative supply/demand balance (after leakage reduction etc)).

Table 14. Country replies on the presence (or absence) of national framework criteria for deciding upon "significant adverse effect on water supply" (Art 4.3) (Mitigation Measures Template on storage)

Do you have national framework criteria for deciding "significant effect on water supply"?	Yes	UK, CY
	No	DK, DE, LT, NO, SK, IE, FI, SE, EE, ES, FR, HU, AT, CZ
	No/Case-by-case	DE, NO, EE, PT
	No/Local criteria	IE
	Not relevant	DK (No surface water used for water supply) FI (Water supply not identified as reason to designate HMWBs) SE (Very few storage schemes for water supply) RO, AT
What level does the framework look at?	National level	CY
	Intermediate level	UK (water supply zone)
What criteria are considered?	Demand supply balance	UK
	Other	NO, CY

Note: No reply from BE, BG, HR, EL, HU, IC, IT, LV, LU, MT, NL, PL, SI.

14.3 Significant adverse effects on wider environment

Significant adverse effects on the wider environment were among the rarest reasons reported in the MMT for ruling out mitigation measures for water storage. In specific, significant adverse effects on the wider environment were only reported by 3 countries (SE for a limited set of mitigation measures (e.g. mitigation of low flow, fish flow, variable flow, rapidly changing flows, physico-chemical alteration, sediment alteration and mitigation of lake level alteration), PT and UK for mitigation measures related to sediment alteration).

The replies may indicate that not much emphasis is placed so far on significant adverse effects on the wider environment or that this is not a significant type of adverse effect of mitigation measures for water storage.

Conclusions

- Significant effects on the wider environment are only rarely a common reason for ruling out mitigation measures in the countries having reported to this activity.
- Significant effects on water use seem to be a common reason for ruling out e.g. flow measures and lake level measures in several countries.
- Few countries (5 out of 17) have reported / set national framework criteria for determining significant effect of mitigation on hydropower. It seems that countries have a different starting point (e.g. flow measures already to a large extent implemented) and understanding of how relevant national criteria should look like.
- It remains unclear how countries that have no relevant criteria or guidelines make sure that there is consistency in decision-making from case to case.
- Consideration of the significance of effect on water use or wider environment is an essential designation criterion for HMWBs and reaching GEP. Therefore, a more harmonised and common understanding on significant adverse effects on water use or wider environment from relevant measures and the starting point in countries needs to be developed as part of the CIS working program. In this context, emerging good practice should be shared also for uses other than water storage.
- Some countries (e.g. AT, SE) have a national indicative estimate/range for reduction of total national power generation that does not have a significant effect on use, while other countries are focusing mainly on cost-benefits and environmental values of measures affecting water use.
- For hydropower, it is key to consider the importance of different benefits (e.g. providing for peaks in demand). Decision-making based only on figures of loss of production does not take into account the timing of energy production from hydropower.

15 Reasons for “outruling” measures

Countries were asked to indicate what they expect to be the most common reasons for ruling out relevant mitigation measure options. The optional reasons for ruling out relevant measures in the MMT were:

- Impact the measure is designed to mitigate not present at all sites (i.e. because of the site's natural reference conditions)
- Technical solution not possible in some sites
- Significant adverse effect on the water use
- Significant adverse effect on the wider environment
- Disproportionately costly
- Not the first choice mitigation measure - normally another mitigation measure likely to be used
- Too early to say which reason is likely to be most common

Overall, only a few countries replied with details to this question (less than 10 countries, with the exception of measures on upstream continuity for which the number of replies was higher). Therefore, it is not possible to fully understand the most common reasons for not requiring mitigation measures due to the small sample of countries that provided relevant information.

Table 15. Most common reasons for ruling out relevant measures not implemented.

Mitigation for		**Technical not possible**	**Significant effect on use/wider environment***	**Disproportiona-tely costly**	**Impact not present at all sites**
Upstream continuity for fish**	**Nb**	**8**	**3**	**6**	**2**
	Countries	AT, DE, EE, ES, FI, FR, RO, PT	AT, SE, RO	DK, SK, UK, IT, CZ, PT	NO, HU
Downstream continuity for fish	**Nb**	**6**	**0**	**2**	**2**
	Countries	DE, NO, FI, SE, ES, FR, CZ		UK, IT, CZ	AT, HU
Low flow	**Nb**	**3**	**9**	**2**	**1**
	Countries	DE, PT, SE	AT, CY, DE, ES, FR, HU, NO, SE*, UK, CZ	PT, UK, CZ	HU,
Fish flow	**Nb**	**1**	**6**	**1**	**0**
	Countries	PT	DE, ES, FR, NO, SE*, UK,	PT	

Variable flow	**Nb**	**1**	**7**	**1**	**0**
	Countries	PT	AT, DE, ES, FR, NO, SE*, UK, CZ	PT	
Rapidly changing flows**	**Nb**	**5**	**5**	**1**	**0**
	Countries	AT, FR, DE, SE, RO	AT, FR, DE, RO, SE*, CZ	NO, CZ	
Lake level alteration**	**Nb**	**5**	**5**	**3**	**3**
	Countries	AT, DE, FI, IT, NO	AT, DE, IE, NO, SE*, UK	SE, UK, CZ	IT, FR, SE
Sediment alteration**	**Nb**	**4**	**7**	**2**	**2**
	Countries	AT, DE, PT, RO	AT, DE, NO, RO, UK*, SE*, PT*	FR, UK, CZ	PT, SE
Ponded rivers (impoundments)	**Nb**	**6**	**3**	**2**	**1**
	Countries	AT, DE, FI, FR, IT, PT	AT, DE, NO	FI, SE	SE
Physico-chemical alteration	**Nb**	**2**	**4**	**3**	**2**
	Countries	FR, PT	DE, ES, SE*, UK	PT, SE, UK	AT, NO

Note: Counts of countries in this table reflect all countries that replied positively with at least one mitigation measure in the specific impact category.

(*) Includes significant effect on wider environment

(**) Fish stocking excluded because this measure is different from the other measures that mitigate more or less directly the impacts from water storage use, while fish stocking compensates the effects of certain impacts on fish fauna instead of mitigating these impacts

Main conclusions

- ”Technical solution not possible in some sites” seems to be among the most widely used reasons for not implementing measures, especially for interrupted continuity for fish and ponded rivers.
- Significant adverse effect on water storage (mainly for hydropower) is a common reason for ruling out some measures, especially measures related to mitigation of flow (low flow, fish flow, variable flow), lake level change and sediment alteration. The decision-making basis for this reason of ruling out measures is not fully clear, as only a minority of countries have a framework of criteria for determining "significant adverse effect on hydropower or water supply".
- Significant effects on wider environment are only rarely a common reason for ruling out mitigation measures in the countries reporting to this activity so far.

- Similarly, disproportionate costs were rarely reported as common reason for ruling out measures. Disproportionate costs were especially indicated as a reason for ruling out the measure “by-pass channels” for upstream continuity. However, disproportionate costs might be a reason for applying an exemption under Art (4) of the WFD, therefore the use of disproportionate costs in connection to the ruling out of mitigation measures in the GEP setting needs to be further clarified.

16 Minimum requirements for GEP and objective setting

Minimum ecological functionality at GEP

Countries were asked to indicate whether the different measure options to mitigate impacts from water storage are necessary as a minimum to ensure the functioning of the ecosystem (as stated in the definition of GEP in WFD Annex V, 1.2.5). Overall, only a few countries replied with details to this question, with the exception of specific measures related to continuity and flow whereby the number of countries providing a response was higher than the average low response rate.

The replies of countries which filled in this part of the template show that:

- The most frequent response for the majority of mitigation measures is that national classification schemes do not identify minimum requirements for ecosystem functioning, therefore the measure(s) cannot be indicated as a minimum requirement.
- Fish passes, the **provision of additional flow** to the river and **mitigation flows for fish migration and variable flow** were the measures most frequently indicated as a minimum requirement in all cases or nearly all cases.

Different country approaches on objective setting for ecological potential

The ECOSTAT workshop on GEP & Water Storage in March 2014 recommended that an aim of intercalibration is to identify a minimum definition of GEP e.g. "you must have water", or "you must have fish" (exceptions may include highland reservoirs or where reference conditions state fish would not be present). If this minimum definition of GEP cannot be met (e.g. because of a significant effect on use), then it is reported as less than GEP and therefore a less stringent objective set (Conclusions of ECOSTAT workshop on GEP & Water Storage, March 2014).

The CIS workshop on Heavily Modified Water Bodies in 2009 concluded that "there must be fish" at GEP. Fish and, in particular migratory species, is seen as a good indicator of ecological continuum. There was general agreement at the workshop that providing river continuum for fish migration is normally a necessary component of good ecological potential.

Overall, there seem to be differences between countries when it comes to minimum requirements for GEP. If further mitigation measures result in a significant effect on use, then UK (Scotland) report this as GEP. Following a different approach, e. g. SE and NO would report such a case as bad ecological potential with a less stringent objective i.e. the environment could be improved but socio-economics dictate that it won't. Both methods follow the WFD but presentationally and politically they are different (Conclusions of ECOSTAT workshop on GEP & Water Storage, March 2014).

Furthermore, in the context of defining minimum requirements for GEP, the general approach used by countries for deriving GEP is important. If the Prague approach is used, certain criteria based on mitigation measures are needed for direct definition of minimum requirements, while with the CIS approach minimum requirements for GEP can be covered by the values of BQEs. A definition of individual measures is thereby not necessary. Nevertheless both approaches can result in comparable minimum values for GEP.

The detailed approach of Norway on the ecological criteria for a functioning aquatic ecosystem to reach GEP is presented in the Box below. We consider this as a relevant example also for other countries and a criteria set combining both GEP-approaches (the CIS reference-based approach and the Prague approach). These criteria are especially relevant to water reaches affected by storage for hydropower.

Box 2 Minimum ecological requirements for GEP – example from Norway

The following ecological criteria for functioning aquatic ecosystem to reach GEP, according to WFD Annex V is defined in the Norwegian HMWB guidance (2014):

1. All quality elements naturally present must be present, but
   - The species composition may be significantly altered
   - Some species or genotypes can be absent
   - Water vegetation can be absent in regulated lakes
2. Crucial ecological functions for life cycles must be present
   - Minimum habitat requirement for rearing and migration
   - A significant part of the WB must have water cover throughout the year
   - Measures (fish stocking, habitat adjustments) can be done to reach the objectives for migratory fish
   - Minimum requirements for migration and distribution for particular important species or stocks (parts of the year). Some of the natural migration possibilities can be replaced by measures (e.g. fish pass, catch and release).

Conclusions – HMWBs impacted by water storage

- In several countries, national classification schemes do not identify minimum requirements for ecosystem functioning, therefore several categories of mitigation measure(s) cannot be indicated as a minimum requirement for ecological functionality at GEP.
- Mitigating low flow is the key measure with highest positive response by countries on being necessary to ensure a functioning aquatic ecosystem.
- Mitigating fish continuity is the key measure with second highest positive response by countries on being necessary to ensure a functioning aquatic ecosystem.

Issues for further clarification

- In future Member State exchange and discussions, it is necessary to clarify some lowest thresholds and minimum requirements at GEP (e.g. BQE success criteria of mitigation measures which most countries consider as obligatory) to ensure the functioning of aquatic ecosystems that are in line with the WFD.
- Is it possible to be at GEP if there is hardly any water in the river? No, a considerable number of responding countries seems to expect a certain level of residual flow or mitigation of significant flow alteration in the water body. Mitigating low flow is the key measure with highest positive response on being necessary to ensure a functioning aquatic ecosystem in all or nearly all cases by 9 countries.
- Is it possible to be reaching GEP if there is no fish in the river (due to missing habitats), where fish should be? No, successful mitigation of fish continuity is the key measure with second highest positive response on being necessary to ensure a functioning aquatic ecosystem. Besides fish, the other relevant BQEs have to be taken into account as well.

- How comparable is ecological quality at GEP between countries? Is it more similar for some water uses than others?
- How to express minimum requirements in general terms and relate the use of mitigation-measures for defining GEP to an ecological terminology in order to be able to monitor the ecological outcomes? GEP has to be described/related also to BQE at the end, independently if the Prague approach ("mitigation measure method") or the original CIS approach is used in countries or combinations of both.
- The BQE results can be monitored with the existing (or adapted) assessment systems.

17 Key findings

A key objective of the exchange of information between European countries on the approaches to achieve good ecological potential in water bodies affected by water storage has been to undertake a comparison of the understanding of the hydromorphological impacts, the measures developed to mitigate them and the reasons for ruling out relevant measures. In the following, we summarise the main findings of the report on these key questions and other important issues related to the comparability of GEP. As there are still differences in the interpretation of several issues by the responding countries, caution is needed when interpreting the results of this exercise.

17.1 Understanding the impacts on ecological condition

- A key finding from the CIS workshops on good ecological potential was that all participating countries were using approaches to achieve good ecological potential by adopting measures which target the ecological impacts resulting from the alteration of habitat conditions caused by water storage.
- The main ecological impacts in HMWBs used for or impacted by water storage were agreed as being (refer also to Table 3 in section 5.1):
    - Reductions in populations of migratory fish due to upstream and/or downstream river continuity.
    - Reduced abundance and/or altered composition of species due to extended loss of wetted habitat under low flows.
    - Impacts on fish productivity due to loss or reduction of flows which trigger migration.
    - Reduced abundance and/or altered composition of species due to an absence of flow variability reducing habitat diversity and causing sediment build-up in sensitive habitats and reduced dispersal of organisms and nutrients.
    - Stranding and wash-out of biota during artificial rapidly-changing flows including hydro peaking.
    - Altered composition and growth rates of primary producers, macroinvertebrates and fish in rivers and lakes due to changes in physico-chemical characteristics such as temperature and dissolved oxygen.
    - Alteration of channel habitats due to disrupted sediment continuity.
    - Reductions in the quality of shallow water and shoreline lake habitats due to artificial changes in lake level.
    - Disorientated fish migration and altered species composition due to reduced flow velocities in ponded rivers.

17.2 Minimum spatial scale of impacts requiring mitigation

- Many countries did not assign a typical minimum length to the impacted reach with some determining it on the basis of the combination of pressures and river behaviour.
- Only 9 of the responding countries identified typical minimum lengths of impacted river reach that would require mitigation.
- There was some variation in the minimum lengths dependent upon mitigation measure but for most measures, the most common minimum spatial scales fall between 0.5 and 3 km of river length.

- There were a few instances where responding countries identified spatial scales of less than 100m or greater than 10km.
- 10 of the responding countries identified typical minimum extents in lake level change that would require mitigation. The most common scale was a change in lake level of less than 1m.

17.3 How comprehensive are the mitigation measures libraries of the responding countries?

- The majority of countries had relevant measures to mitigate all of the ecological impacts that they identified.
- There is a small proportion of countries which have yet to identify measures on a significant proportion of the impacts they have identified (see Figure 7).

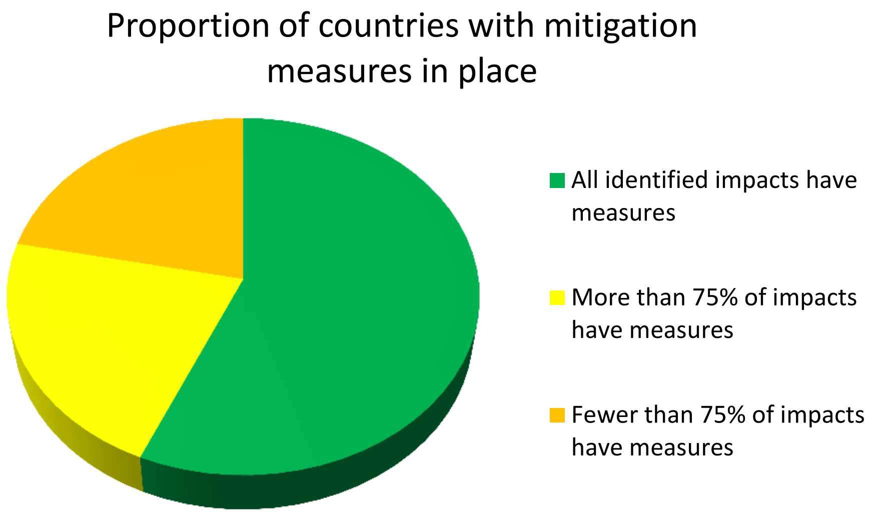


Figure 7. The proportion of countries with mitigation measures in place for impacts identified.

17.4 Assessing the degree of similarity between responding countries on impacts and mitigation measures

The key findings related to the similarity between countries on impacts and measures were that:

- The most frequently identified impacts due to water storage were the risks to upstream and downstream fish migration, an absence of a viable minimum environmental flow and insufficient flow variability.
- The measures most commonly identified in countries' libraries were those to support upstream and downstream fish migration.
- The type of measure most consistently ranked as having the highest priority across the responding countries was the provision of fish passes to support the upstream migration of fish.
- The highest level of heterogeneity across all responding countries was seen in the measures aimed at mitigating physico-chemical alteration, rapidly changing flows, sediment alteration and ponded rivers.

High alignment Moderate alignment Low alignment		Impacts and mitigation		
Mitigation measure	Impact identified	Use of measure	Type of highest ranked measure	No of countries identifying the need for this mitigation
Upstream continuity for fish			Fish Pass	21
Downstream continuity for fish			Bypass channel	21
Low flow			Provide additional flow	18
Fish flow			Flow for up and downstream migration	14
Variable flow			Actively delivered flow	18
Physico-chemical alteration			Multiple reservoir intakes	12
Rapidly changing flows			Reduce rate of flow change	15
Sediment alteration			Introduce mobilising flows	15
Lake level alteration			Reduce abstraction during sensitive period	15
Ponded rivers (impoundments)			Lateral reconnection	13

Table 16. The degree of similarity between responding countries on impacts due to water storage and the measures to mitigate them.*

**The green shading indicates that at least two thirds of countries' responses were the same; yellow indicates alignment in between one and two thirds of respondents and orange is where less than one third of responses were the same. However, all 23 countries have not completed all information needed (see Table 2 for country response).*

17.5 Assessing the degree of similarity on ecological and practical effectiveness of measures

- There was a high degree of consensus that the provision of additional flows would likely be highly ecologically effective to mitigate low flows.
- Measures to mitigate the impact of ponded rivers were identified by a relative small group of countries so far but most of these identified the lateral reconnection of floodplain features, the construction of bypass channels and reducing storage level as highly ecologically effective.
- The measures which were most frequently identified as likely to be most practically effective[5] were the provision of additional flow to mitigate low flows and the introduction of variable flows to mobilize sediment.
- In general there was more similarity between countries in the assessment of the ecological effectiveness of measures than their practical effectiveness and adverse effect on use.

17.6 Comparability of criteria to select/rule out mitigation measures

- ”Technical solution not possible in some sites” seems to be among the most widely used reasons for not implementing measures, especially for interrupted continuity for fish and ponded rivers.
- Significant adverse effects on water storage (mainly for hydropower) is a common reason for ruling out some measures, especially measures related to mitigation of flow alteration (low flow, fish flow, variable flow), lake level change and sediment alteration. However, only a minority of countries have a framework of criteria for determining significant adverse effects on hydropower, and even less for water supply.
- Significant effects on wider environment are rarely a reason for ruling out mitigation measures in the countries reporting to this activity.
- Similarly, disproportionate costs were rarely reported as common reason for ruling out measures.

17.7 Assessing similarity on adverse effect on water use

- Overall, most responding countries consider that many types of mitigation measures have no effect or low effect on the use of water storage.
- There was high degree of consensus by those countries which identified fish passes for upstream fish migration and multiple reservoir intakes for mitigating physico-chemical alterations that these would have a low effect on the water use.
- In the same time, significant adverse effects on water storage (mainly for hydropower) is a common reason for ruling out some measures, especially measures related to mitigation of flow (low flow, fish flow, variable flow) and lake level change.
- Overall, it is not transparent so far how significant adverse effect on use is being defined, as few countries have reported / set national framework criteria for determining significant effect of mitigation on hydropower. It remains unclear

[5] Practical effectiveness refers to the extent to which measures are self-sustaining (high practical effectiveness) or require regular maintenance (low practical effectiveness).

how countries that have no relevant criteria or guidelines make sure that there is consistency in decision-making from case to case.

17.8 Minimum ecological requirement for GEP

- A considerable number of responding countries seems to expect a certain level of residual flow or mitigation of significant flow alteration to ensure a certain water depth in the water body in combination with continuity for fish (if relevant). So, the statement from previous CIS discussions on HMWBs "there must be fish" seems still to be valid.
- The most frequent response for the majority of mitigation measures is that national classification schemes do not identify nor specify minimum requirements for ecosystem functioning for GEP (according to WFD Annex V).

18 Conclusions and recommendations

18.1 GEP is possible to harmonise

Comparing the mitigation expected for good ecological potential by different countries provides a good basis for identifying similarities and differences between those countries' standards for good ecological potential. It also provides a valuable opportunity for the exchange of information.

There is a high degree of agreement across Europe on the typical impacts that can result from the different types of water storage schemes. The mitigation that countries believe should at least be considered in relation to the main impacts of water storage schemes is also similar.

A considerable part of differences in the replies of countries is probably caused by the different GEP definition methods applied (CIS-based approach, Prague method or a combination of both). However, similar results can be the outcome of applying the different methods, if there is a comparable understanding of selection and ruling out of measures for definition of GEP. Ultimately, all approaches include a definition of GEP based on BQE.

As a consequence, where impacts are similar, good ecological potential is likely to be comparable. Therefore, it is concluded that a harmonisation of the environmental objective for HMWBs impacted by water storage is possible. Confidence in this conclusion is greatest for countries whose methods for GEP definition are more advanced. These tend to be countries with significant numbers of water bodies affected by hydropower schemes.

The GEP harmonisation exercise presented in this report has served as a pilot to test whether and how a harmonisation is possible to carry out. The procedure presented in this report can be used for harmonising GEP and HMWBs designated for other water uses. In this context, a comparison of the results from the different methods used for defining GEP seems to be possible.

Recommendation 1: It is important to develop and agree on a generalised framework for deciding on the mitigation required for good ecological potential (flow-chart describing the relevant considerations to be used in this decision-making process). Such a generalised framework can be used to supplement CIS Guidance no. 4 on HMWB.

Recommendation 2: The type of approach presented in this report can be used for harmonising GEP and HMWB designated also for other water uses, on the way to establishing environmental requirements for water biota in HMWBs according to the WFD.

Recommendation 3: Further clarification is needed on the reasons for heterogeneity across countries on identified impacts and measures used for mitigating especially the following: physico-chemical alterations, rapidly changing flows (hydro peaking), sediment alterations and impacts from ponded rivers (impoundments).

18.2 Common terminology

Undertaking this exercise required development of a common terminology for the different types of water storage schemes, their impacts and mitigation measure. This reduced misunderstandings and facilitated the exchange of information.

Recommendation 4: It is recommended that any similar future exercises under the Common Implementation Strategy include the step of agreeing a common technical terminology.

18.3 Emerging good practice

Experience in the practical use of different mitigation measures is variable. The country exchange on mitigation measures for water storage impacted water bodies indicates those measures which have been deemed to be the most effective at moderating the ecological impacts of water storage. These measures should be used subject to the constraints of being technically feasible and not leading to significant adverse effects upon the water use and the wider environment.

Several of these mitigation measures are also relevant for mitigating impacts other than water storage (e.g. restoring the ecological continuum at barriers due to road constructions).

Furthermore, an optimal combination of good practice mitigation measures (see table below) might even lead to the achievement of GES, and avoid designating water bodies as HMWBs. In such cases, the measures can be considered as restoration measures. The extent of ecological improvement depends on the specific combination of measures applied and the level of their implementation taking into account national criteria/thresholds for assessing significant adverse effects of measures on the use/wider environment. An example for this could be a river impacted by water storage without other severe morphological alterations present, where measures for eflows (low flow + dynamic flow + fish flow) in combination with fish migration aids are sufficient for the achievement of GES.

Emerging good practice on the mitigation measures that should be considered for water storage is identified in the following table. In general, most of the measures are related to mitigation in impacted rivers, and less to mitigation in lakes/reservoirs used for water storage. In order for the emerging good practice measures to achieve ecological improvements in the long run, it is crucial to take into account the importance of maintenance (so that measures function properly) and principles of adaptive management (e.g. measures may need to be adapted in view of climate change).

The following measures form a core part of the emerging good practice.

Mitigation measures of the emerging good practice for rivers impacted by water storage schemes	
Upstream and downstream passage for key fish species at dams and water intake structures	• Where there is an interruption in the continuity of fish migration, fish migration aids like fish ladders, bypass channels (both up and downstream) or exceptionally fish lifts should be used dependent on site specific characteristics • Screens or fish friendly turbines are recommended if there is a risk of fish entering turbines (downstream)

	• If all other measures are technically infeasible, trap, transport and release might be the only viable option for GEP.
Low flows	• A key measure is mitigating low flow conditions by providing additional flow (with large variation but concentrating in the range of Q92 to Q97). These additional flows should ideally be adapted to site characteristics e.g. by considering habitats and/or ecological criteria. • Where such low flow mitigation cannot be fully implemented due to significant adverse effects on the use, river morphology changes (including sediment management) to make best use of available flow can be employed.
Flow variability	• If absent, a variable/dynamic component of the flows downstream of the impoundment should normally be introduced.
Fish flow	• For long distance migrators, this measure should include suitable flows timed to trigger/support upstream & downstream migration.
Rapidly changing flows (hydro peaking)	• Reducing the rate at which the discharge ramps down • Relocation of tailrace • Improving in-channel structures to reduce velocities and provide shelter • Installing external balancing reservoirs
Sediment transport	In general there is little experience in implementing these mitigation measures. Emerging good practice includes: • Introducing mobilising flows and/or sediment downstream • Restoring lateral erosion processes (e.g. by removing bank fixation to enable sediment erosion, reconnecting floodplains).
Ponded rivers (impoundments)	• Constructing bypass channels (impounded reaches and barriers) to create a flowing habitat • Reducing storage level to increase flowing water habitat (raising bed) • Reconnecting tributaries / floodplain features • Making improvements to in-channel habitats. This is most effective in reaches with some flow or in combination with other mitigation creating flowing habitat
Mitigation for physico-chemical alteration	There are promising case studies in some countries however in general there is little experience in

	implementing these measures. Potential measures include: • Flexible or multiple intakes to ensure abstraction occurs at relevant water depth in reservoirs. • Managing lake level (reservoir) in sensitive periods to mimic more natural water temperature (e.g. ensure ice cover) in the downstream river can be an option.
Mitigation measures of the emerging good practice for lakes/reservoirs used for water storage	
Mitigation of lake level alteration	• Reduce abstraction to restrict the amplitude of level change in ecologically sensitive periods • Increased inflows, if possible, to minimise the impact of abstraction • Improve connectivity to tributaries and, where required, create embayment(s) • Overall, although mitigation of lake level alteration is important, it has to be balanced against potential adverse effects on the use

Recommendation 5: Countries that are still developing their methods are strongly recommended to take account of the emerging good practice on mitigation measures identified in this report.

18.4 Minimum requirements for GEP or use of exemptions in HMWBs

If no flow can be provided in a river without a significant effect on the benefits served by a water storage activity, it could be argued that the river can nevertheless be classified as good ecological potential (GEP) in case there is no common understanding on minimum ecological requirements for GEP. However, this would potentially be confusing for the public and not in line with the expectation of the WFD that there is some approximation to ecological continuum at GEP.

Recommendation 6: It is recommended that, if no mitigation is possible but impacts are so severe as to prevent basic ecosystem functioning, a water body should not be classified as good ecological potential but classified as moderate or worse and application of exemptions should be considered.

In this context, it should be reinstated that according to the WFD, heavily modified water bodies (HMWBs) are a separate water category and not a type of exemption. For example, disproportionate costs might be a reason for applying an exemption under Art (4) of the WFD, if achieving GEP is not realistic. However, if disproportionate cost for measures is used in connection to the ruling out of mitigation measures in the GEP setting, further clarification is needed on the decision-making process for exemptions in HMWBs.

Recommendation 7: Minimum ecological requirement for GEP is an issue that needs further clarification, to ensure that designation of water bodies as heavily modified cannot be equivalent to an exemption (less stringent objective than GEP). It is important that Member States clearly describe the minimum criteria for GEP to make it more transparent. In this context, consensus on ecological minimum criteria for GEP should be developed. If the Prague approach is used, direct minimum ecological requirements based on measures can be used, while in the CIS approach minimum requirements can be covered by the values of BQEs.

18.5 Clarify criteria for determining significant adverse effects on water use

One of the reasons why the standard for ecological potential can vary between water bodies and between countries is that it depends on what can be done by way of improvement to the hydromorphological characteristics of the water body without a significant adverse effect on the benefits served by the water storage activity. Consequently, decisions on when such adverse effects are significant are important.

Recommendation 8: It is recommended that each country establishes criteria for deciding if mitigation would have a significant effect on the use of water storage and other water uses through a clear and transparent process. This is a precondition for understanding the degree of harmonisation of GEP, as well as designation for HMWBs.

Although few countries have made their criteria public, the limited evidence available suggests that the thresholds for considering effects as significant are very similar between countries. For example, in the case of effects on hydropower generation, they appear to be in the range 2% to 4% of the national output.

At the same time, several countries are referring to a case-by-case approach to define the significance level even for adverse effects upon hydropower. It is still unclear how most countries cope with significant effects on the use.

Recommendation 9: It is recommended that as part of the CIS a dedicated workshop series is needed to ensure common understanding, transparency and sharing good examples on effects on use vs. significant adverse effects on water use and wider environment relevant for HMWB designation and implementation of mitigation measures.

The mitigation requirements incorporated into water storage schemes (e.g. existing flow requirements) during their original construction vary between countries. To achieve the same standard for good ecological potential, countries where very limited mitigation was incorporated face a much larger relative effect on the benefits provided by their water storages schemes than do countries where considerable mitigation was embedded from the start.

Recommendation 10: To avoid significant adverse effects, it is recommended that countries with an unfavourable starting point use the river basin planning process to decide where and how to prioritise improvements.

18.6 Spatial scale and relevance of impacts

Among countries with well developed methods, the scales of impacts considered sufficient to affect the status of a water body are similar (generally in the range 0.5 to 3 km). However, there is some considerable variation around this and the majority of countries have not reported any national criteria on scale. If biologically indicated impacts are used on a comparable water body size, fixed criteria on length are not necessarily needed to compare results.

There needs to be further clarification on whether the typical minimum length of impacted river reach, water body size or lake level change that would require mitigation is interpreted by countries similarly to the assessment of the significance of impacts. This is especially relevant for countries with very large water bodies. It should also be clarified whether the scale of impacted river reach or lake level change refers to hydromorphological or biological impacts or both.

Recommendation 11: It is recommended that, as part of its planned work on hydromorphology, the ECOSTAT Working Group provides an opportunity to better understand how countries take account of spatial scale in deciding on the ecological relevance of alteration of hydromorphology.

18.7 Applying national methods to a common set of HMWBs

The conclusion of the exercise presented in this report is that, for similar water bodies affected by similar water storage schemes, the ecological potential is likely to be comparable between at least those countries with more advanced methods for GEP definition in prioritized catchments. It would be possible to improve confidence in this conclusion by applying different countries' national methods to a common set of water bodies/catchments impacted by water storage. Such an exercise would also be valuable in further identifying and elaborating on emerging good practice, clarifying scaling issues, implementation of measures in practice and possibly also for handling multiple pressures and intercalibrated EQRs/methods related to e.g. pollution in a comparable way.

Recommendation 12: It is recommended that the Common Implementation Strategy agrees to an exercise to compare the outcomes produced by countries' national methods by applying them to a comparable set of heavily modified water bodies. Consideration should then be given to incorporating the results of both exercises into a good practice guide. There is probably a need to supplement CIS Guidance no. 4 on HMWB with an appendix based on this exercise, to ensure common environmental requirements in HMWBs.

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List of abbreviations and definitions

AWB	Artificial water bodies
BQE	Biological quality element
CIRCABC	Communication and Information Resource Centre for Administrations, Businesses and Citizens
CIS	Common Implementation Strategy
CSWD	Commission Staff Working Document
Eflow	Ecological flow
ECOSTAT	WFD CIS working group dedicated to the ecological status of surface water bodies
GEP	Good ecological potential
GES	Good ecological status
HMWB	Heavily modified water bodies
Hymo	Hydromorphology
IC	Intercalibration
ICOLD	International Commission On Large Dams
MEP	Maximum ecological potential
MMT	Mitigation measure template
MW	Mega-Watt
NGO	Non-governmental organisation
RBD	River Basin District
RBMP	River basin management plan
TWh	Tetra-Watt hour
WFD	Water Framework Directive
WG	Working Group
WISE	Water Information System for Europe

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KJ-NA-28413-EN-N

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Publications Office

doi:10.2760/649695

ISBN 978-92-79-64994-3