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Heavily regulated lakes and the European Water Framework Directive - Comparisons from Finland, Norway, Sweden, Scotland and Austria

ABSTRACT

The Water Framework Directive (WFD) has reformed EU water legislation by introducing a new approach for water resources management. The WFD includes a specific category for water bodies which are hydromorphologically substantially altered. Hydro power is one of the most important pressures in many water courses especially in Fennoscandia and in some parts of Austria and Scotland. In the joint study which was carried out together with Austria, Finland, Norway, Scotland and Sweden the need and opportunities for common approaches in regulated and constructed water courses were studied. In the project, the role of the hydro power and water level fluctuation in some regulated lakes were analysed as well as the opportunities to improve regulation policies according to current legislation. In addition, the procedures and criteria for provisional identification of heavily modified water bodies were compared and discussed during the project. The use of same indicators proved to be problematic as there are big differences in availability of required data and lake specific hydro-morphological conditions vary a lot in different countries. However, 3 m regulation amplitude or winter draw-down was used as a provisional identification criterion in Finland, Norway and Sweden. This was the consequence of the information exchange and frequent discussions. The provisional designation is only one phase in the designation process and subsequent phases finally determine the number of heavily modified water bodies and required mitigation measures. Therefore, it is evident that the need for harmonization increases in the whole EU-level in the future.

Keywords: Water Framework Directive, heavily modified water bodies, water course regulation, mitigation measures, hydro power

1. INTRODUCTION

The Water Framework Directive (WFD) has reformed EU water legislation by introducing a new approach for water resources management. The primary aim of the directive is to improve the ecological status of rivers and lakes and prevent further deterioration of those

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watercourses which already show good ecological status. WFD allows Member States to identify surface waterbodies which have been hydromorphologically altered by human activity as "heavily modified" under specific circumstances. For those water bodies the objective is the achievement of a good ecological potential which may strongly deviate from good ecological status. The Commission has emphasized the importance of coherent and effective implementation of the WFD.

Heavily modified waters were thoroughly studied in the EU CIS (Common Implementation Strategy) Working Group 2.2 for the identification and designation of Heavily Modified Water Bodies (HMWB). 34 case-studies were undertaken by the member states on trial catchments using provisional outline guidance papers prepared by the HMWB working group. The outcomes of the working group were the CIS guidance document with a separate book (tool box) summarizing several case studies (Kampa & Hansen, 2004). As a part of that work, a hydropower subgroup was established to focus on the issues relevant in water bodies where the major human pressure is hydropower. The hydropower subgroup continued as an unofficial forum for information exchange after the work of CIS 2.2 working group ended. The following countries have participated in the activities arranged by the group: Austria, Finland, Norway, Scotland and Sweden. This article is mainly based on the information which has been collected, analyzed, discussed and presented in the four separate meetings of this hydropower subgroup during 2003 and 2004.

The scope of this article concerns regulated lakes and reservoirs, although in many cases works carried out in rivers downstream and upstream have significant impact on the status of the lake or reservoir. The hydropower subgroup has attempted to answer the following questions:

- What are the objectives and magnitude of the watercourse regulation in each country? What is the role of hydropower for national electricity production systems?
- What are the similarities and differences in characteristics of regulated lakes and reservoirs in different countries? What are the main ecological impacts of lake regulations?
- What are the major differences in the identification of hydro-morphological pressures and provisional designation of water bodies?
- What are the opportunities to modernize old regulation licenses and what kind of projects have been realized?
- What kind of mitigation measures have already been carried out and what are the conclusions after these experiences?

In this article, we use the term "target countries" when we refer to the countries represented in the hydropower subgroup and from which lake regulations and practices have been analyzed. The reservoir is used here to describe a body of water, either natural or man-made, used for storage, regulation and control of water resources.

This article is structured in a following way: first, we present the data which our analysis is based on, how the data was gathered, and what kind of methods were applied during the study; second, we discuss the history, magnitude, and objectives of watercourse regulations especially in Scandinavian countries, including a description of opportunities and recent aspirations to modernize old regulation practices; third, we analyze hydro-morphological alterations in different countries as far as it is possible taking into account the data received from each country; fourth, we present and discuss the procedures which were applied for the provisional identification of heavily modified lakes; fifth, we compare the mitigation measures which have been applied in different countries in order to diminish the adverse impacts of lake regulations; finally, we draw some conclusions where we pinpoint major similarities and differences in conditions and practices, identify major research needs, and present guidelines for the further implementation of WFD in the regulated water courses.

2. MATERIAL AND METHODS

This article is based mainly on the data which has been gathered during the work of the unofficial hydropower subgroup during 2003-2004. In addition to discussions and presentations in the group, the material is based on a questionnaire and water level analysis of regulated lakes. Through the questionnaire we gathered general information about the watercourse regulation and the state-of–the-art related to implementation of the Water Framework Directive in physically heavily modified water bodies. Questionnaires were submitted to key persons in charge of implementation of WFD in Austria, Finland, Norway, Sweden and Scotland in the beginning of May 2004 and updated in the beginning of the 2005.

Analysis of water level fluctuation is based on daily water level values from several lakes in the target countries excluding Austria where no data was available. From each country two lakes were selected for further analysis. As there is a big variation in lake regulation practices in each country, the results of this narrow analysis cannot be generalized. However, it can give a rough picture of the similarities and differences in water level fluctuation of regulated lakes between target countries. General physical characteristics of lakes and other relevant information are gathered in Table 1.

Table 1: Main hydrological features of the research lakes. Finnish lakes: 1 = Lake Oulujärvi, 2 = Lake Kemijärvi; Swedish lakes: 3 = Lake Vänern (Sjötorp), 4 =Lake Suorvajaure; Norwegian lakes: 5= Lake Øyeren, 6 = Lake Breidalsvatn.; Scottish lakes: 7 = Lake Quoinch, 8 =Lake Oich

	1. Oulu-järvi	**2. Kemi-järvi**	**3. Vänern**	**4. Suorva-jaure**	**5. Øyeren**	**6. Breidalsvatn**	**7. Quoich**	**8. Oich**
Area (km^2)	887	285	5648	260	73.3	6.9	nd	nd
Mean depth (m)	8.4	5.2	27 (106 max)	ca 30	14 (76 max)	- (45 max)	nd	nd
Total water volume (km^3)	7.2	1.4	153.0	5.9	1.274	0.07	nd	nd

	1. Oulu-järvi	2. Kemi-järvi	3. Vänern	4. Suorva-jaure	5. Øyeren	6. Breidalsvatn	7. Quoich	8. Oich
(km³)				(regulation volume)				
Drainage area (km²) 1)	19 800	27 400	46 884	4650	39 900	137	nd	nd
Mean discharge (m³/s)2)	230	325	518	155	685	6	nd	nd
Water level data, regulated (years)	1980-99	1980-99	1980-99	1980-99	1983-2002	1983-2002	1992-97	1991-99
Water level data, natural (years)	1980-1999*)	1980-1999*)	1900-1919**)	1980-1999*)	-	-	1930-1945**)	1931-1933**)

1) Drainage area measured from lake outlet, 2) Mean discharge at lake outlet. Water level data: *) re-calculated, **) measured.
nd – missing data

Water levels of target lakes were analyzed by using REGCEL water level analysis – model, which was developed in Finnish Environment Institute (SYKE) between years 1999-2000 (Hellsten et al. 2002). With the help of REGCEL –model it is possible to calculate values for more than 50 water level parameters which describe indirectly the impacts on the littoral fauna and flora, some fish species and those birds which build nests near the shoreline. In addition, some parameters describe the impacts on scenery and on different forms of recreational use. Due the limitations of available background material, only the following indicators were calculated in every study lake.

- Winter draw-down, which is calculated as a difference between the highest (W_max between 1.Nov.-30.Apr.) and the lowest winter (W_min between 1-Nov – 30-Apr) water level.
- Ratio between winter draw-down and mean depth of the lake.
- Change in average summer (1-Jun - 31-Aug) water level due to the water level regulation.
- Short-term regulation during recreational period (1-Jul – 31-Oct) maximum absolute value of daily change in water level.
- Short-term regulation during recreational period (1-Jul – 31-Oct) calculated as as the number of differences >10 cm in daily mean level from one day to another.

3. DESCRIPTION OF WATER COURSE REGULATIONS

3.1 Magnitude and objectives

Water level regulation is related to the human need to control the water levels of the lakes and flows of the rivers in such a way that benefits various users of watercourses (Sundborg, 1977). There is a large variation in regulation practices depending on the primary objectives of regulation. However, in slightly or moderately regulated watercourses the natural hydrology has still a central role in defining the actual water level fluctuation.

In a typical hydropower regulation project in the northern hemisphere, water levels during summer period are normally high or rising, while during the winter period, when the need for electricity is normally at its highest, the water level is strongly lowered. Flood prevention regulation follows a similar pattern during winter time, but in summer time some storage capacity is left empty to catch flash floods. When the major objective of the regulation is recreation or navigation, then regulated water levels are often more stable than natural ones. If the water level is regulated for water supply use, the water level fluctuation is more irregular and depends on the specific use of raw water.

In Finland, Norway, and Sweden, there are thousands of lakes, both natural and regulated (Table 2). If we consider only those lakes greater than 0,5 km^2, Sweden is the most lake rich country with 7 260 lakes (Table 2). In Finland and Norway, the number of lakes which area is more than 0,5 km^2 is almost the same, ca 4 500. In contrast to that, in Austria and Scotland there are only few lakes, e.g. in Austria the number is 62.

There are hundreds of regulated lakes in Finland, Norway and Sweden (Table 2). For instance, in Sweden, there is 563 lakes larger than 1 km^2 with water level regulation vary from 0.1 m to 35 meters. In Norway, there are approximately 800 reservoirs registered in NVE's database, and a further 100 are assumed to exist without being registered so far. In half of these reservoirs, the water level fluctuation is more than 5 metres. The highest regulation amplitude is 140 m. In Finland, the water levels from 100 regulation projects of the total 350 projects have been analysed. Finnish regulations are usually relatively mild in terms of annual water level fluctuation. Half of these projects show that the annual water level fluctuation is less than 1 metre. The maximum water level fluctuation in the most heavily regulated lake in Finland is 7 metres.

Relative proportions of regulated lakes to the total number of lakes is the lowest in Finland (8 %) and the highest in Scotland (46 %), where the combination of high altitude and high precipitation favours establishment of reservoirs. However, in Finland, most of the largest lakes are regulated and consequently one third of the total lake area (about 11 000 km^2) is regulated.

In summary, many Swedish and Norwegian reservoirs are much more heavily regulated than Finnish ones. However, the regulation amplitude itself does not directly describe the magnitude of ecological impacts of regulation. For instance, in Finland lakes are generally much shallower and their water is more coloured and consequently the productive zone is narrower than in Norwegian and Swedish lakes. Furthermore, there is a big difference in the use of regulated watercourses between Finland, Sweden and Norway. In Sweden and Norway most reservoirs are located in remote areas where recreational use of the watercourse is usually of minor importance, whereas in Finland the regulated lakes are almost always important for recreational purposes. For instance, there are thousands of recreational users and fishermen in Lake Kemijärvi, which is the most heavily regulated lake in Finland (Marttunen & Hellsten 2003).

Table 2: Number of water bodies used for regulation purposes and main reasons for water level regulation based on interview.

	Number of water bodies			**Main purpose of water level regulation projects (%)**					
	Lakes (> 50 ha)	Regulated lakes and reservoirs	Share of regulated lakes and reservoirs (%)	Hydropower	Flood prevention	Recreational use	Water supply	Navigation	Timber floating
Austria	62	13	21	100					
Finland	4 500	350	8	40	25	4	25	1	
Norway	4 491	> 900	> 20	95			3	1	1
Sweden	7 260	-	0	-	-	-	-	-	-
Scotland	324	118*	46	91	5	2		3	

* estimation, - data is missing

The importance of the hydro power production varies a lot in different countries. In Norway 99 % of electricity is generated by hydro power, in Austria the proportion is ca 70 %, in Sweden ca 50 %. In Finland and Scotland the proportion is much smaller, around 15%. In Finland, most regulation projects serve several purposes (Table 2). For example, the objectives of hydropower production and flood protection are broadly in line with the water level drawdown during the winter (Marttunen et al., 2001). In Austria, Norway and Scotland, most regulation projects serve primarily for the purpose of the hydropower production. However, in some Norwegian and Swedish projects also flood prevention is playing a significant role. Hydropower is an important interest especially in northern and high altitude lakes where there usually exists no other pressures, whereas regulations for navigation and recreation purposes are located in lowlands lakes situated at densely populated areas.

3.2 Characteristics of regulated lakes and ecological impacts of lake regulation

The characteristics of regulated lakes vary largely within and especially between the study countries. Finnish regulated lakes lie in lowland areas with elevation less than 250 metres above sea level, and are relatively shallow with average depths of about 7 metres and gently sloping shores. Furthermore, their water is usually quite coloured (dark) with average secchi depth less than 3 metres. In Norway, Sweden and Scotland, many regulated lakes lie in the highlands and have oligotrophic character with secchi depth more than 5-10 metres. The slopes of these lakes are also steep. Due to the differences in altitude and latitude of lakes, there are also differences in the biology of the lakes. For instance, in large Finnish regulated lakes there are usually about 15-20 fish species whereas in the high land lakes in Norway the fish fauna consists of few salmonid species, or fish are not found at all.

The ecological effects of water level regulation on lakes have been studied intensively in Sweden in 1960's and 70's (e.g. Grimås, 1962; Sundborg, 1977; Nilsson 1981), in Norway in 1980's (e.g. Rørslett, 1988) and in Finland during last 20 years (e.g. Alasaarela et al.,1989; Palomäki, 1994; Hellsten, 1997, 2001).

Changes in the water level fluctuation regime cause significant changes in the littoral, which is the most visible part of the lake ecosystem for normal lake users. When the water is transparent, the negative effects of a fluctuating water level are less severe than in the case of turbid or coloured water, due to the wider productive zone (Rørslett, 1988; Alasaarela et al., 1989; Palomäki, 1994, Hellsten, 1997).

The littoral undergoes considerable geomorphologic changes during the initial stages of lake level regulation, especially if the mean water level is raised (Sundborg, 1977;, Rørslett, 1988; Alasaarela et al.; 1989). This leads to major geomorphologic changes, including breakdown of the organic surface layer and erosion of minerogenic matter. However, the increase in erosion has a negative effect on the littoral vegetation and benthic fauna, which leads to the decreased littoral production noted in the first studies of heavily regulated Swedish reservoirs (e.g. Grimås, 1962; Nilsson 1961). These erosional processes cause destruction of vegetation and affects the successional status of the vegetation, as reported in several Scandinavian lakes (Nilsson, 1981; Rørslett, 1985).

As a result of winter draw-down, the ice layer may extend down to the bottom, causing the sediment to freeze and to be partly eroded by scouring (Renman, 1993; Palomäki & Koskenniemi, 1993; Hellsten 1997). Great losses in the production of autumn spawning fish and benthic fauna are well known to be a consequence of ice extension (Huusko et al., 1988; Tikkanen et al. 1988; Palomäki, 1996). However, there are still open questions concerning how the changes in reproduction affect the fish stocks.

As the water level is kept relatively low during the early spring, the maximum water level during the spring flood has been lowered remarkably in many regulated lakes in Scandinavia and it tends to shift towards late June (Alasaarela et al., 1989). On the other hand, in many reservoirs there is a substantial reduction or even almost total elimination of flood peaks downstream. In the lakes, the changes in spring flood water levels affect the reproduction of spring spawning fish, because most of the spawning areas are not accessible during the spawning period. However, it also has a negative effect on the early stages of young fish fries of autumn spawning fish, which have to find shelter among littoral vegetation (Selin & Hakkari, 1982).

The vulnerability of the lake to regulation depends on its water quality and morphological characteristics (Palomäki, 1994; Hellsten, 1997). The same regulation amplitude has wider environmental effects in a lake with a limited productive zone than in a clear water lake with extensive littoral zone. On the other hand, gently sloping shores are more resistant to erosion than steep ones, usually found in mountainous zones with clearer water.

3.3 Development of old regulation projects

Most of the lake regulation projects in the target countries have been carried out after World War II. In Finland, Norway and Sweden the most intensive construction period was between 1950 and 1970. Nowadays, in Finland, the potential for development of new hydropower is fairly limited due to the fact that most of the remaining rapids are protected by special act. However, there are some plans to increase the capacity of old power plants and to build small-scale plants. In Sweden, the situation is fairly similar to Finland and there are plans to build small-scale plants in rivers with existing regulation. In contrast to Finland and Sweden, Norway, Scotland and Austria have some active plans to increase hydropower production.

Most of the regulation projects are now 40-60 years old. Nowadays, the use of watercourses and values of societies have changed. For instance, the importance of agriculture has decreased and recreational use of watercourses has increased considerably. In addition, our knowledge about the ecological impacts of regulation and how to diminish harmful impacts have improved due to much research.

In Finland, Norway and Sweden, the current legislation allows the revision of old regulation practices, thus determining new conditions or limitations on reservoir operation. However, there are differences in the license review practices. The modernization of the old regulation projects has been active and systematic especially in Finland (Marttunen et al., 2001).

The constancy of regulation licenses varies in target countries. In Finland, the regulation licenses of the old regulations (started before 1991) are permanent. However, the amendments in the Water Act in 1994 enabled the revision of those regulation licenses which cause significant harmful impacts on aquatic environment or recreational use. One major precondition for the revision is that the total benefits of the regulation should not diminish remarkably. Since 1994, about 80 regulation development projects have been launched. In these projects, the impacts of water level fluctuation have been assessed as well as possibilities to diminish harmful impacts of regulation. The alteration of regulation practice has been a common outcome in these processes. Restoration and mitigation measures were proposed in more than half of the projects. Other measures undertaken were, for instance, protection of shorelines, fish passes, embankments and bottom weirs. Recommendations which dealt with monitoring of the impacts of these measures and communication were also generally presented.

Norwegian law states that after 30 years of operation (50 years for schemes built before 1972), the environmental conditions connected to a publicly owned hydropower scheme can be reviewed and changed. This process is called "licence review", and it comprises a complete review and upgrading of environmental aspects based on experience gained over the first decades of operation. Several of the large hydropower schemes built during the post-war period of 1945-71 are publicly owned, and reviews have also started on the newer schemes with 30-year review obligations. As a consequence of both these situations, many reviews of license conditions will be carried out from now until 2022 for most post-war hydropower schemes. This comprises a large proportion of all schemes currently operating in Norway. The period 2005-2022 happens to occur at a time when Norway is also in the process of implementing the WFD, and the review process will naturally include the future WFD requirements and procedures. The main intention of such reviews is to improve the environmental conditions in affected reservoirs, rivers and fjords.

In Sweden, the revision of regulation license is possible if the conditions have changed after the start of the regulation. The process which aims at revision of regulation licenses is called as "omprövning". The Swedish state can, on behalf of the public, apply revision if there are general environmental or health reasons for that, if environmental quality standards are being exceeded or if the revision improves fishery. However, the revision must not obstruct concerned operations in a substantial way. This approach has been applied in some cases. In some cases, the process has resulted in the changes in fish compensations. The process has not lead to the revision of the regulation license. However, target water levels have been defined on a voluntarily basis.

4. HYDRO-MORPHOLOGICAL ALTERATIONS AND THEIR ASSESSMENT

4.1 Hydromorphological elements in the WFD

The Water Framework Directive describes hydromorphological quality elements of lakes as hydrological regime and morphological conditions. Bragg et al. (2003) identified the following aspects of WFD implementation where lake hydromorphological data would be required:

1. Defining lake types, and subsequently for assigning surveyed lakes to the appropriate types (Article 5 and Annex II, 1.3)
2. Identification and assessment of pressures and impacts (Annex II, 1.4/5), which in turn would provide information for one of the early stages of screening for HMWB (Heavily Modified Water Body) status.
3. Environmental objectives: preventing deterioration and restoring morphology to support good ecological status (Articles 1, 4 / Annex V); measures to ensure morphological conditions are consistent with the required ecological status (Article 11(i)).
4. Monitoring, especially surveillance monitoring (Article 8).

Hydromorphology is thus important not only for defining water bodies at high status, and for investigating possible reasons for water bodies failing to reach good ecological status (GES), but also has an important role in designating and establishing appropriate monitoring strategies for HMWBs and Artificial Water Bodies (Rowen et al., 2004).

Hydrological regime and morphological conditions in lakes are divided in the WFD (Annex V) into following elements:

- Hydrological regime: The quantity and dynamics of water flow, residence time, connection to the groundwater body.
- Morphological conditions: Lake depth variation, quantity, structure and substrate of the lake bed, structure of the lakeshore.

On the other hand, the division between hydrological regime and morphological conditions are difficult to draw, because e.g. level and depth variation are highly dependent on each other. In the WFD context, lake depth variation is included in the morphological conditions although, in many cases, it reflects changes in hydrological regime.

Morphological alterations include usually dams and weirs affecting also the ecological continuity of rivers situated downstream from the lake. Fish passes have been built to many rivers. In Norway and Sweden they are common in major salmon rivers, but not in higher dams and high mountain dams. In Finland, there are only a few fish passes in major regulated rivers. Usually, the fish passes have been built in the lowermost power plants near the sea. In Norway, the absence of the fish pass (thus blocking access to spawning grounds) has been considered justification to consider the downstream water body as HMWB, but not the upstream lake or water bodies further upstream.

Especially flood protection works and drainage of flood plains have produced embankments, which can significantly change morphology of lowland lakes. Such lakes, which are often artificial or created by damming of coastal shallow basins, are quite typical e.g. in the Netherlands. Generally, large scale morphological alterations are more common in small lakes surrounded by agricultural areas and population centres.

4.2 Criteria for hydromorphological alterations

A wide variety in the monitoring and documentation of hydromorphological alterations in the target countries has been observed. In Finland, there is good data on hydrology both from regulated and natural lakes. However, the morphological pressures and changes, which in many cases have only minor impacts, are poorly documented (Marttunen et al., 2001). In Scotland, the development and testing of Lake Habitat Survey (LHS) method has improved remarkably knowledge about morphological alterations (Rowan et al., 2004). In Scotland, the hydrological data is available only from regulated lakes. In Sweden, hydrological records cover all large regulated lakes, such as lakes Vänern and Vättern, but in natural lakes only the discharge of the lake outlet is followed. In Norway, water levels of all reservoirs and regulated lakes are recorded, whereas water level fluctuations of natural lakes are usually not registered (Rørslett, 1988).

The summary of hydromorphological alteration criteria applied in target countries is presented in Table 3. The most generally applied indicator for hydrological pressure is annual water level fluctuation which is applied in 3 of 5 studied countries. In Finland as well as in the Norway, the winter draw-down is applied too. In the Finnish regulated lakes, the correlation between winter draw-down and annual water level fluctuation is high. However, the winter draw-down has been used as a criterion as the link between biota is clearer than in the case of regulation amplitude. Hydrological load, which means the change in the amount of the inflow to the lake, was applied only in Norway. Only in Finland short term regulations has been used as alteration criteria.

Dam/weir structures, change in depth and surface area and also lateral embankments are quite typical criteria used as alteration index, whereas dredging works and bridges and terraces are important in every second country (Table 3). As a curiosity, canalization for ship traffic is significant only in Scotland whereas modification of lake outlet by drilling a tube via lake bottom (lake taps) is only typical in Norwegian high altitude reservoirs.

4.3 Comparison of water level fluctuation

In Finnish regulated lakes, the annual water level fluctuation is usually 1-3 m. There are two major types of lake regulations. In the Southern and Central Finland, the highest water levels have been lowered (Fig. 1.AB), whereas in the Northern Finland the water level has been raised in order to increase storage capacity (Fig. 1.CD). In both cases, during the wintertime the water level is decreased in order to increase the hydropower production and to vacate storage for the spring flood. During the summer, the water level varies usually less than in the natural state. The fluctuation of water level is also more regular; that is, there is not as big a difference in water levels between hydrologically dry and wet years as there was in the natural state.

Table 3: Use of hydromorphological alteration criteria in target countries.

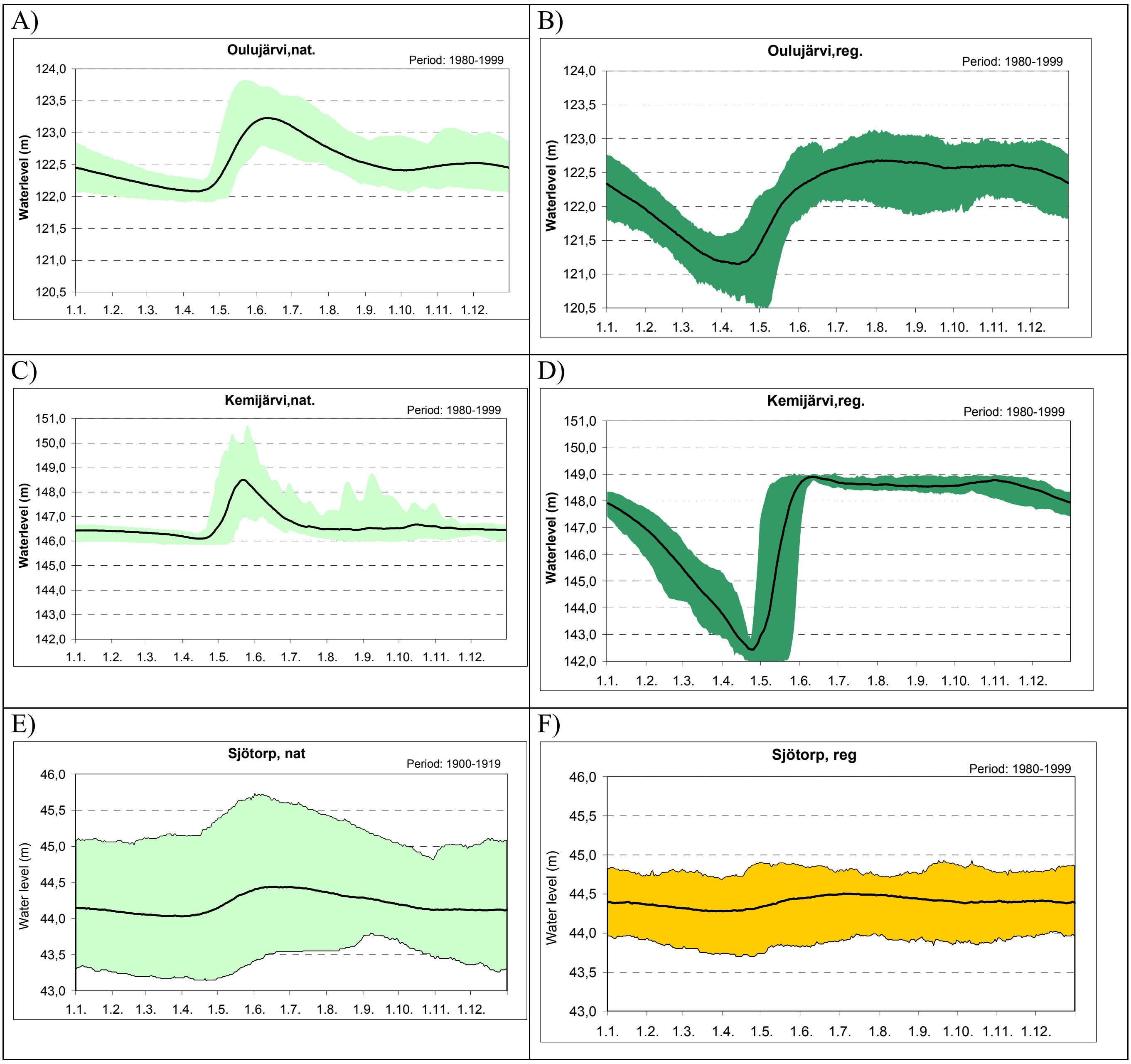
	Austria	Finland	Norway	Sweden	Scotland
Morphology					
Embankments	x	x			x
Dredging		x			x
Canalisation					x
Bridges and terraces		x			x
Dam and weir structures	x	x	x	x	x
Lake taps*)			x		
Significant change in depth and surface area	x	x	x		
Hydrology					
Annual water level fluctuation	x		x	x	
Winter draw-down		x	x		
Water level rise or draw-down		x			x
Short term regulation		x			
Hydrological load**)			x		

*Lake taps refer to specific reservoirs where lake outlet is transformed to tube situated at the bottom of lake.

**) Term refers to cases where due to river diversion natural retention time has been significantly changed

In Sweden and Norway, high altitude mountain lakes are heavily regulated and the regulation amplitude is very large, whereas lakes in lowland areas are usually weakly or moderately regulated. Water level fluctuation of different lakes and reservoirs resembles significantly each other in Fennoscandinavian hydropower reservoirs such as lakes Kemijärvi, Oulujärvi, Suorvajaure and Breidalsvatten (Fig. 1). Water level draw-down takes place during the ice covered period and spring flood fills the reservoir quite rapidly. Usually, the water level is kept near the upper level for the summer period although in some lakes very slow increase may occur.

Scottish lakes differ greatly from Scandinavian ones, because water level is at highest during winter time. Differences between hydrologically different years are very significant especially in regulated Loch Quoich. Loch Quoich is now controlled by a dam and operated as a long-term storage with a large annual rise and fall. Loch Oich today has no dam, and the structure at its outfall is thought to be the same as in the 1930s. The hydrological difference between the two periods is that, in the 1990s, much of the upstream catchment is controlled for hydroelectricity plant, whereas there was no upstream power plant in the 1930s.



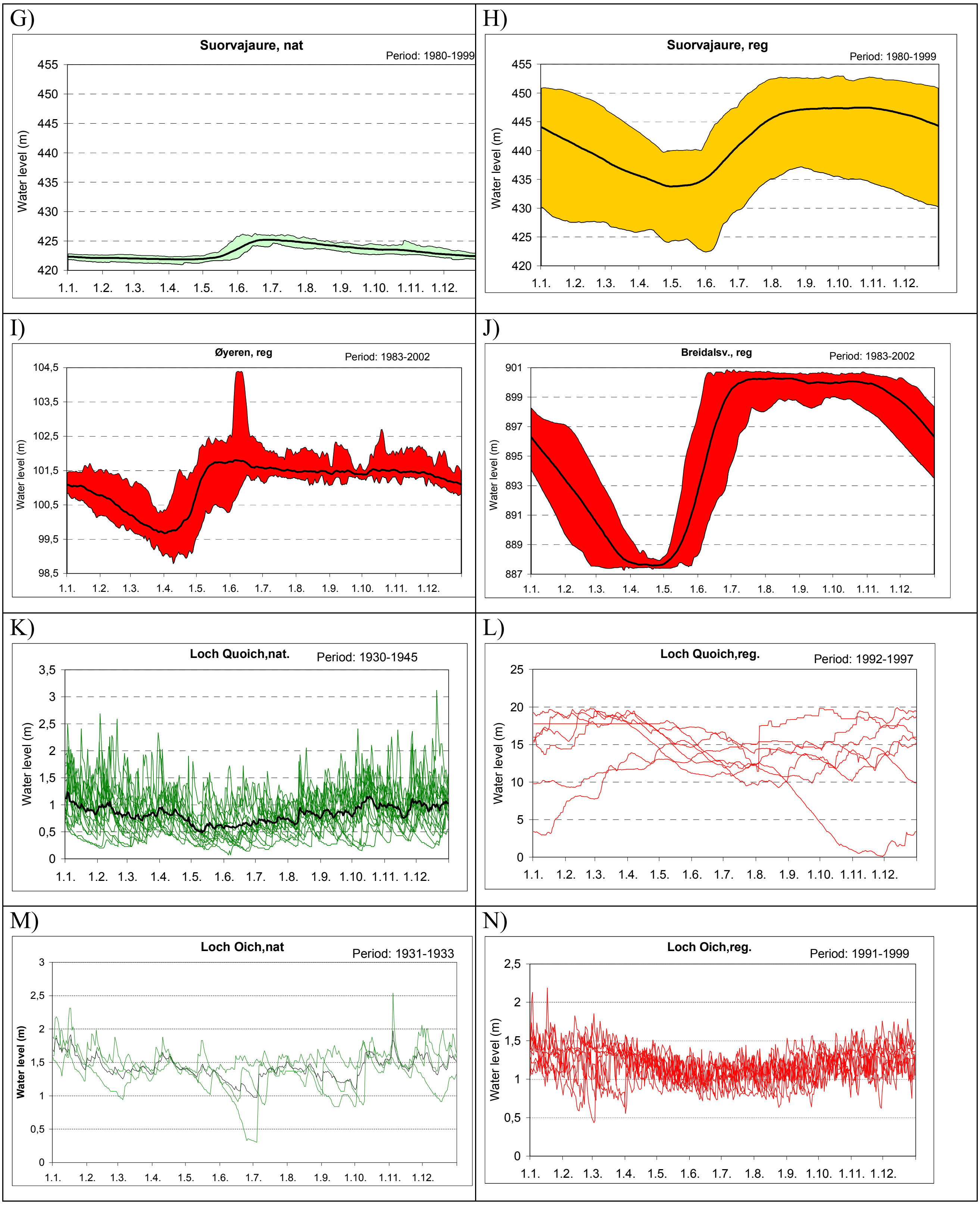


Figure 1: Natural and regulated water level fluctuation in some study lakes. Lake Oulujärvi, natural (A), regulated (B), Lake Kemijärvi, natural (C), regulated (D), Lake Vänern, natural (E), regulated (F), Lake Suorvajaure, natural (G), regulated (H), Lake Öyeren, regulated (I), Lake Breidalsvatn, regulated (J), Lake Quoich, natural (K), regulated (L), Lake Oich, natural (M), regulated (N).

Water level analysis was performed for all lakes and we try to use in the comparison the same criteria which were used in the provisional identification of Finnish heavily modified lakes (Table 4). However, lack of data (e.g. ice melting day, secchi depth) prevented us using the same criteria in the comparison. Furthermore, water level fluctuation in Scottish lakes differs significantly from the Scandinavian lakes, and the use of same criteria was not reasonable.

In several regulated lakes in Finland, Norway and Sweden, water level regulation practices are quite similar and the same indicators can be used. Winter draw-down was significant in most of the lakes except in Lake Oich (UK), where it was only moderate, and in Swedish Lake Vänern (Sjötorp), where there was no winter drawdown effect. The regulation of Lake Vänern is designed to increase hydro power generation and to improve conditions for navigation.

Table 4: Main water level fluctuation indicators used in study (See methods for details)

	Winter draw-down (m)	**Proportion of winter draw-down to mean depth (%)**	**Water level rise (m)**	**Short term regulation (%) **)**	**Status (provisionally heavily modified (pHMWB) or not)**
Finnish criteria for moderate change	1.5	> 25	> 1	10	
Oulujärvi	1.6	19	-0.4	1	not
Kemijärvi	6.6	128	1.8	0	pHMWB
Vänern	0.3	-	0.1	0	not
Suorvajaure	13.7	-	18.0	28	pHMWB
Øyeren	2.4	-	-	7	not
Breidalsvatn	12.7	-	-	8	pHMWB
Quoich	7.4 *)	-	-	33	?
Oich [1)]	1.1	-	-	37	not

[1)] Natural lake, there is a hydro power plant upstream which affects the water level fluctuation of the lake.

*) Annual water level fluctuation. – No data available **) proportion of days when the water level fluctuation in a day has been greater that 0,1 m in the study period (%)

The proportion of winter draw-down to mean depth was very difficult to calculate because the mean depth data was missing from other countries except Finland (Table 4). In Finland, the proportion was significant in Lake Kemijärvi and moderate in Lake Oulujärvi.

The water level rise indicator suffered also due to lack of information from Norway and Scotland (Table 4). In this dataset, it was significant in lakes Kemijärvi and Suorvajaure and minor in lakes Oulujärvi and Vänern (Sjötorp).

Parameters describing short-term regulation were available in all regulated lakes (Table 4). Lake Oich was an exception of all lakes, because very significant daily change in water levels were observed both before and after regulation. Very significant short-term regulation was observed in Lakes Øyeren and Oich. Lakes Breidalsvatten, Suorvajaure and Quoich have also big value in short-term regulation but values are caused by annual water level change.

Applying of Finnish water level analysis tool seems to fit partly on Norwegian and Swedish lakes although quite many essential parameters are missing. However, it did not fit to Scottish lakes, where water level fluctuates quite rapidly and lakes are not usually covered by ice.

5. PROVISIONAL IDENTIFICATION OF HEAVILY MODIFIED LAKES

The designation of heavily modified water bodies will be carried out in two phases. The provisional designation has to be undertaken by March 2005, and the designation phase by 2009. In the provisional designation phase, the aim was to identify those water bodies where physical pressures have caused substantial changes in the characteristics as well as in the ecological status of the water body. In the final designation phase, the definition of ecological status and the opportunities to achieve good status are the main subjects of interest.

In many water bodies, there is lack of systematically gathered biological data. Besides, there are many open questions related to the classification of water bodies according to the WFD. Therefore, a method that was based on the use of indirect criteria has been applied in every target country in the provisional identification of heavily modified regulated lakes.

The approaches to identify heavily modified water bodies vary substantially among target countries. In Finland, the aim was to identify only those lakes which most probably will be designated heavily modified in later phases of the process. In contrast to Finland, Norway will identify also uncertain cases and include them as provisional HMWB candidates. In Scotland, the lakes were divided into five groups: no risk, low risk, at risk, high risk, no data available. In Austria, there were three groups: not at risk, at risk and decision not possible due the lack of knowledge. The criteria for provisional designation of lakes in target countries are presented in Table 3.

The most common criterion is the annual water level fluctuation. It is taken into account in all target countries except in Finland. In Finland, a corresponding criterion, winter draw-down, which is strongly correlated with annual water level fluctuation, is used. The rise of the water level was applied as a criterion in Finland, Norway and Scotland. However, there was a big difference in the threshold value of that criterion between different countries. Only Finland and Scotland have used both hydrological and morphological criteria in the provisional identification.

Norway has developed a large number of specific screening criteria in order to rapidly assess which water bodies should be selected as provisional candidates for HMWB selection. Comparisons made with corresponding criteria used in other member states reveals that there are a greater number of criteria used in Norway to define heavy modifications to hydro-morphology than in neighbouring countries, and alpine countries with similar climatic and topographic conditions (Fig. 1 and Table 3). The reason for this observation can probably be found in the fact that there are several hundred rivers and lakes affected in Norway by the development of hydropower, giving a wide variation in the technical approaches used to develop each potential site. For instance, there are numerous inter-basin transfers in mountain regions which significantly affect the hydraulic load (water residence time) in natural lakes found downstream. This in turn affects water level variations, pH, alkalinity, eutrophication risk, water temperature and ice cover in a way that makes it impossible to achieve the natural lake ecological status (HES) without removing the inter-basin transfer. With the wide variations existing in climate, topography, nutrient content and pH in site-specific conditions found in the 1 500 HMWBs identified in Norway, it was considered necessary to cover a wider number of hydro-morphological changes with more elaborate criteria than in other countries.

Table 5: Comparison of criteria used in Finland and Norway for preliminary identification of candidate HMWBs.

Criteria	Finland	Norway	Sweden	Scotland
Lakes				
Impoundment and regulation zones	> 3 m drawdown Proportion of winter draw-down is more than 66 % from the mean depth of the lake	Active annual regulation zone >3m Raised lake levels >10 m	Damming amplitude > 3 m Lake directly up-streams of a hydro-power plant ≥ 20 MW	Annual water level fluctuation, rise of water level;
Morphology	> 50% of shoreline is protected from erosion	Artificial change in wetland water level >50 cm		
Effects of water diversions	-	Lowland lakes with changed residence time (hydraulic load) by a factor of 5 or more causing changes to or from eutrophic state		
Rivers				
Reduced flow	Mean high/low flow has been changed > 50 %	No by-pass stream diversion; extended downstream until 75 % of natural flow is regained Rivers where min. flow is set at <20 % of Q_{95}		
Hydro peaking	Max discharge variation in short time regulation > mean annual discharge	Discharges regulated > 5 % per hour relative to max turbine flow.		
Morphology	> 50 % of river- stretch is dredged (or "straightened")	-Dredged, straightened or altered stretches with more than 1km continuous length or >50 % of both riverbanks modified under normal water level		

Criteria	Finland	Norway	Sweden	Scotland
Reduced floods	-	Mean annual natural flood occurs < every 20 years		
Temperature/ ice-cover	-	Deep intakes or water transfers result in lack of ice-cover/ water temp. always > +co1^0 C		
Rivers to Lakes				
Damming	Reach of damming > 50%	Rivers which are impounded to form a lake with a surface area >0.5 km^2 or raise water level by >5 m	Damming amplitude > 3 m Lake directly up-streams of a hydropower plant ≥ 20 MW	
Lakes and Rivers				
Salmon lakes and rivers	-	Water transfers or upstream regulation causing: * Turbidity changed from <0.5 to >2.0 FTU * pH lowered by more than 0.5 to <5.5		

It is interesting to compare the threshold values of those criteria which are applied in several countries. For example, in Finland, Sweden and Norway the same threshold value, 3 meters, were applied for the annual water level fluctuation although the ecological impacts of that magnitude regulation probably deviate significantly between different countries due to the differences in the water quality and steepness of the littoral zone. Furthermore, considering that the Norwegian regulated lakes usually are found in the high mountain eco-zone with steep shorelines and freezing conditions for more than half of the year, such a difference can be expected. Experience from a wide number of lakes in Norway indicates that maintaining a littoral shallow-water vegetation zone around the lakeshore (and thereby a natural lake ecology) is very seldom possible with large depths of the winter drawdown, which regularly exposes the lakeshore to prolonged freezing conditions. In Finland, the lakes are more humic and shallower than in Norway and as a result consequent impacts of similar regulation amplitude on aquatic ecosystem are more negative.

The target countries have arrived at very different threshold values for water level rise criterion. In Finland, where the shores of the regulated lakes are quite gently sloping, the threshold value is 1 meter, whereas in Norway and Scotland, where the slopes are usually much steeper, the values are 10 meters and 5 meters, respectively. Smaller impoundments in these latter countries seldom lead to a permanent deterioration in ecological status after a period of readjustment to the new lake level. However, these same lakes are usually pHMWB candidates anyway, due to seasonal drawdown being the initial cause of the impoundment.

In Finland, the method developed for provisional designation of regulated lakes has also been used to identify lakes with high hydrological status (Keto et al., 2003). Up to present, this identification method has been applied to 105 regulated lakes. The range of lakes investigated has been relatively large, varying from 2 km^2 to 1 100 km^2 with a mean size of 88 km^2. In 20 % of the study lakes the hydrological regime resembles totally or nearly totally undisturbed conditions and thus can be classified with high hydrological status.

6. MITIGATION AND RESTORATION METHODS IN REGULATED LAKES

There are various methods to improve the ecological status of regulated lakes. Among the most popular in the studied countries are: alteration of regulation policy, fish stocking, habitat restorations, protection of erosion shores and constructing drowned weirs (Table 6). In different countries, a little bit different mitigation and restoration practices have been adopted.

The most commonly used mitigation measure in Finnish lakes is fish stocking. In many regulated lakes, there are obligations to stock certain amount of fish or to put certain amount of money to into stocking fish. Brown trout, pikeperch, whitefish and pike are the most important stocked species. The effectiveness of fish stocking has varied a lot. For instance, the stocking efficiency of brown trout is highly dependent on the available food resources (e.g. Marttunen and Vehanen, 2004). Generally, the results have been at least moderate and in most regulated lakes the total unit catch (kg/ha) does not deviate from natural lakes. During recent years, there has been a tendency to increase the stocking of fingerlings and fish eggs and to mimic the natural reproduction cycle as much as possible. It should be noted here that there are some regulated lakes where no fish compensation measures are determined so far.

In Norway, the most common mitigation and restoration methods so far adopted have been establishment of fish hatcheries and stocking of regulated lakes, and the specification of minimum flow releases for rivers, often combined with the construction of artificial weirs to form pools in the river bed. Naturally, there are also a wide range of other mitigation measures adopted for special situations, but they are not discussed in this article.

Fish stocking of Norwegian lakes has been commonly imposed as an environmental mitigation condition of the licence issued for regulating the river, known as the “concession”. The primary objective is usually to improve fish catches both for recreational fishing and for commercial harvesting of fish resources, as a substitute for losses of natural stocks in the lake or elsewhere in the catchment. This measure is directed at one species only, almost exclusively either salmon or trout. Experience shows that the best results are usually achieved where poor recruitment is or has been a constraining factor.

In Sweden, attitude toward fish stocking has not been as positive as in Finland and Norway. As a result, stocking has been restricted to much more limited areas. As a curiosity, it can be mentioned that fresh water shrimp *(Mysis relicta)* has been introduced to some tens of regulated lakes in order to improve the food resources of fish especially in high altitude reservoirs in Sweden (Sundborg, 1977).

Table 6: Mitigation measures applied in regulated lakes.

Mitigation measure	Finland	Norway	Sweden
Alteration of water level regulation practice	***	*	*
Stocking fish into the lakes	***	***	**
Restoration of lake habitats	*		
Protection of erosion shores	**		*
Drowned weirs (in order to reduce water level fluctuation of sub-basins)	*		
Introduction of new species (e.g. food resources)	(*)		(**)
Artificial littoral zone		*	
Fertilization	-		*
Revegetation (planting e.g. willows to littoral zone)	*		

*** Commonly used, ** Used in some cases, * Used only in few cases , (*/**/***) not used anymore, - Not used

7. CONCLUSIONS

This article has mainly paid attention to the comparison of criteria for provisional designation of HMWB a subject for much discussion during 2003 and 2004. After the reporting to EU in March 2005, attention is turning to the forthcoming phases in which these criteria may have only minor importance. However, it is possible that the final designation may still be based on a combination of these criteria and expert judgment, since the biological data to assess the ecological status may be inadequate in many cases.

One aim of this study was to find opportunities for common approaches in the identification of heavily modified water bodies. The study provided a good arena for discussions and information exchange with experts of different countries. However, in practice the national implementation in each country was done independently of this study and there was limited opportunity for arriving at a common approach. This was partly due to the limited time as the national implementation process was carried out to strict deadlines at the same time as this study. As a result, the process of how physically heavily modified water bodies are provisionally identified differs from country to country.

Our experience suggests that it is good that there are a common procedure and general principles which can be followed in different countries. On the other hand, our project pointed out that the water course regulation systems and the vulnerability of the lakes to hydromorphological alterations are different from country to country. Therefore aspiration toward common criteria and threshold values is not necessary. The use of the same water level indicators proved to be problematic as there are big differences in availability of required data and lake specific hydromorphological conditions vary a lot in different countries. However, one provisional identification criteria, three metres regulation amplitude (or winter draw-down) was used in Finland, Norway and Sweden. This was the consequence of the information exchange and frequent discussions.

Furthermore, the use of common criteria in provisional designation phase was not considered necessary, since subsequent phases finally determine the number of HMWBs and required mitigation measures. In the later phases of WFD implementation, the harmonization of practices will have a more crucial role, since the environmental objectives and minimum requirements for mitigation measures in the heavily modified water bodies should be about the same in different countries.

We believe that only after the improved understanding of local or regional characteristics, including intercalibration of lake typology, it will be possible to analyze the possibilities for a common HMWB identification approach during the implementation of European WFD. More comparisons and research are needed based on better data on the ecological status.

One interesting finding of the project was that in Austria, Finland, Norway and Sweden there are mechanisms in legislation which allow the mitigation of harmful environmental and social impacts of regulation projects. The processes which have been launched based on the current legislation have many similarities with WFD. The difference is that the WFD is "thematically narrower" than the current license reviews. For instance, according to the Finnish Water Act the modernization process aims at alleviating harmful impacts of regulation both to the aquatic environment and to water use, whereas, the WFD focuses on ecological improvements. The role of stakeholder involvement is also emphasized in the legislation.

There is a potential dilemma between the objectives of the WFD (nearest possible pristine ecology) and the aims of local people. For instance, in Finland most mitigation measures carried out so far have aimed to improve the opportunities for recreational use. The aims of these measures and the objectives of WFD can be sometimes opposite. One potential conflict is that local people want more stocks of salmonid fish to catch and from the WFD point of view it would be recommendable to restrict the fishing in order to ensure that spawning stock is large enough.

Experiences, methods and results of earlier projects are highly applicable in the implementation of WFD. For instance in Finland, 80 regulation development projects have been undertaken and methods, experiences and results are highly applicable in the implementation of WFD as well. Public participation and stakeholder involvement have played an important role in many of those projects. The experiences suggest that it has been possible to manage conflicts and reconcile opposite objectives of various stakeholders especially in projects where stakeholders and citizens have had an opportunity to actively participate the planning and decision making processes.

In Finland, large lake regulation development projects have lasted usually 4 years. In the implementation of WFD, more straightforward processes are needed and opportunities to gather new information of the ecological, social and economic impacts of regulation are relatively limited due to the large number of projects going on at the same time.

One major issue in the future is how to improve the ecological status of regulated lakes and especially the conditions in the littoral zone. A more detailed synthesis of experiences from different mitigation measures used in regulated lakes would be useful in order to enhance the capacities to assess the potential impacts of different mitigation measures on the ecological status.

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