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Heavily Modified Waters in Europe

A Case Study of Lake Kemijärvi, Finland

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Photo: Dense *Carex*-vegetation at sheltered shoreline of Lake Kemijärvi,
Seppo Hellsten

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Preface

Introduction by Joint Chair

In accordance with Article 4 (3), the Water Framework Directive (WFD) allows Member States to identify surface water bodies which have been physically altered by human activity as "heavily modified" under specific circumstances. If the specified uses of such water bodies (i.e. navigation, hydropower, water supply or flood Adefence) or the "wider environment" would be significantly affected by the hydromorphological changes (restoration measures) required to achieve good ecological status and if no other, technically feasible and cost-effective, better environmental options exist, then these water bodies can be designated as "heavily modified" and good ecological potential is set as an environmental objective.

As part of the EU WFD Common Implementation Strategy (CIS), a working group has been established to develop guidance on the process of HMWB designation. The CIS working group 2.2 on "Heavily Modified Water Bodies" (HMWB) is jointly managed by the United Kingdom and Germany and involves the participation of the 12 Member States (MS)[1], Norway, some Accession Countries[2] as well as a number of Stakeholders[3]. A number of distinct "sub projects" were progressed by the Working Group:

- production of 12 "guidance papers" by the joint chair of the HMWB WG that were discussed at several Working Group meetings;
- thirty-four case study projects, carried out in the MS and Norway, that tested the "guidance papers";
- production of a synthesis of the case study reports;
- production of a HMWB guidance document along with a policy summary and a toolbox supporting the guidance document.

Based on the main uses within the case studies, two "case study subgroups" were established, one concentrating mainly on "navigation", the other one on "hydropower". The Working Group members and/or contractors responsible for these case studies exchanged their experiences during their work in extra subgroup meetings and in email discussion fora.

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[1] Austria, Belgium, Denmark, Spain, France, Germany, Greece, Netherlands, Portugal, Sweden, Finland and UK

[2] Hungary, Poland and Slovenia. The other seven Accession Countries are also members of the group but have so far not attended a working group meeting or the workshop.

[3] EEB, EUREAU, Eurelectric and WWF.

Production of 12 guidance papers

The joint chair of the HMWB WG produced 12 guidance papers covering the key aspects of the HMWB identification and designation process. Four meetings were organised involving the Working Group members and the European Commission to discuss and agree on these guidance papers and to exchange experiences. These were held on 12th April, 10th October 2000, 4th September 2001 and 18-19th June 2002 in Brussels. The guidance papers were to help the production of the case studies which tested these papers and also served as the basis for the guidance document.

Case Study Project

In thirty-four case studies from different Member States and Norway a draft provisional identification and designation process for heavily modified water bodies was tested supported by reference to the guidance papers . In these case studies, ecological reference conditions (maximum ecological potential) and objectives (good ecological potential) for HMWB were also established, as far as possible. The case studies focused on the main specified uses (navigation, flood/coastal protection, hydropower generation, agriculture, forestry, urbanisation, recreation and water supply) that result in physical alterations across the MS. The case studies covered mainly rivers, only a few case studies were carried out on coastal waters (1), estuaries (2) and lakes (3). The case study projects started in October 2000 and were finalised in June 2002. The WG has not necessarily endorsed the approach taken by any individual case study. It should be noted that the case studies have not strictly followed the approach of the HMWB guidance document since most of them were completed before the issuing of the final agreed guidance.

European Synthesis Project

The synthesis project performed an analysis of the case studies and a synthesis of approaches taken in the individual case studies, identifying commonality and differences in approach. The synthesis project formed the basis for the production of the guidance document and the toolbox, providing examples of different designation approaches.

Production of the Guidance Document, Policy Summary and Toolbox

Based on the draft synthesis report and on the twelve Working Group papers prepared by the Joint Chair (UK and D) and discussed during the first three meetings of this WG, a first draft guidance on the designation of heavily modified and artificial water bodies was produced on 27 May 2002. A workshop was held on the 30-31st May 2002 for Working Group members, case-study managers, and the other CIS WG members to discuss a number of outstanding issues of the HMWB draft guidance document. The discussions during the workshop served as a basis for the revision of the draft guidance document. A second draft was discussed at the last WG meeting in June 2002. The final version was sent to the meeting of the Strategic Coordination Group (SCG) in September 2002 and submitted to the Water Directors Meeting in November 2002.

The policy summary is an executive summary of the HMWB guidance document, addressed to the Water Directors. The document summarises the main issues of the HMWB and AWB designation process and is derived directly from the guidance document. It was sent to the SCG together with the guidance document in September 2002.

The guidance document is supported by a toolbox with practical examples from the case studies illustrating the different steps of the HMWB and AWB designation process. Working Group members were asked to provide additional examples that help illustrate certain steps of the guidance document. It is planned to issue the final toolbox by December 2002. The toolbox does not constitute part of the guidance document and is hence not subject to the agreement of the HMWB Working Group.

Joint Chair of the CIS HMWB WG 2.2 (UK/D)

October 2002

Introduction by Authors

Kemijärvi case study was one of the thirty-four case studies from different Member States and Norway. These case studies formed the basis for the work of HMWB working group. The case studies were carried out in the guidance of working group. This report follows the constructions prepared by the Joint Chair. In the national level the project was guided by the VESPORA- steering group chaired by Risto Timonen (Ministry of Agriculture and Forestry). The progression and results of the project were also presented in several workshops and working group meetings. Furthermore, the project was carried out in close co-operation with Lake Kemijärvi regulation development project.

Kemijärvi case study was funded by Finnish Environment Institute, Ministry of Forestry and Agriculture (project number 310019) and TEKES (National Technology Agency of Finland) Luomujoki-project. Work has been done in strict co-operation with Lake Kemijärvi lake regulation development project chaired by The Lapland Regional Environment Centre. Some additional field works and GIS-analyses were done by Elise Järvenpää, Mika Visuri and Sari Partanen. During the project we had several fruitful discussions with several experts in research institutes and power companies on the rocky road of WFD. Particularly, we will thank Antton Keto, Anne Tarvainen, Jukka Muotka, Minna Torsner, Heikki Hämäläinen, Teppo Vehanen, Martti Rask and Heidi Vuoristo. We will also thank the whole VESPORA steering group and especially its chairman Risto Timonen for his valuable support during the project. We would like to thank Zach Shelby for revising the English of preliminary version of manuscript.

Mika Marttunen and Seppo Hellsten

March 2003

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Summary Table

Below is the summary table provided in the kick-off meeting of the European project on heavily modified water bodies (Table 1).

Table 1. Summary table of the Finnish key study

	Item	Unit	Information
1.	Country	text	Finland
2.	Name of the case study (name of water body)	text	Kemijärvi
3.	Steering Committee member(s) responsible for the case study	text	Seppo Hellsten, Mika Marttunen
4.	Institution funding the case study	text	Finnish Environment Institute, Kemijoki Ltd., the National Technology Agency (TEKES), Ministry of Agriculture and Forestry
5.	Institution carrying out the case study	text	Finnish Environment Institute, Lapland Regional Environment Centre
6.	Start of the work on the case study	Date	April 1, 2000
7.	Description of pressures & impacts expected by	Date	November 1, 2000
8.	Estimated date for final results	Date	December 1, 2001
9.	Type of Water (river, lake, AWB, freshwater)	text	Lake
10.	Catchment area	km^2	27 285
11.	Length/Size	km/ km^2	80 km, 128 – 285 km^2
12.	Mean discharge/volume	m^3/s or m^3	311 m^3/s, 200 – 1300 milj.m^3
13.	Population in catchment	number	25 000
14.	Population density	Inh./km^2	1
15.	Modifications: Physical Pressures / Agricultural influences	text	Water level regulation (max. 7 m), water level uplift by 2.2 metre in 1965 and dam constructions due to flood protection and hydropower production
16.	Impacts?	text	Changes in littoral vegetation, benthic fauna and fish populations
17.	Problems?	text	Erosion of sandy shores, remnants of terrestrial vegetation
18.	Environmental Pressures?	text	Demands for changes in regulation practice by local population
19.	What actions/alterations are planned?	text	Development of milder regulation practice
20.	Additional Information	text	Many mitigation measures already done (shore restoration, fish stocking etc.)
21.	What information / data is available?	text	Vegetation, benthic fauna, fish population, hydrology
22.	What type of sub-group would you find helpful?	text	Hydropower case study-group
23.	Additional Comments	text	

Introduction

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3.1 Choice of Case Study

In Finland the majority of larger lakes are regulated and nearly all large watercourses have been exploited, primarily to meet the needs of hydropower production and flood protection. The total area of regulated lakes is almost 11 000 km^2, equalling one-third the total area of Finnish inland waters. Since the 1950s and 1980s, when most of the regulation began, significant changes have occurred in the use of watercourses and in society as well. During the last decade there has been pressure to change the regulation of several lakes, and extensive research projects have been carried out in different parts of Finland on the effects of regulation and methods for mitigating its negative impacts (e.g. Hellsten *et al.* 1996, Marttunen & Hellsten 1997, Marttunen *et al.* 2001).

The EU Water Framework Directive (WFD), which came into force at the end of 2000, will also create new pressure to assess the ecological impacts of regulation and the need and potential for revising regulation policies and carrying out mitigation measures. The WFD permits Member States to designate water bodies as "heavily modified" where structural and hydrological alterations have caused considerable changes in biological elements (e.g. in macrophytes, zoobenthos or fish fauna). The requirements for ecological status can be substantially lower for heavily modified waters than for slightly modified or natural water bodies. The big question is which regulated lakes and rivers are heavily modified and which are considered natural.

The designation process will be carried out in two phases. In the first phase heavily modified water bodies are first designated or identified as far as possible on the basis of information on biological changes in the water systems. However, because of limited biological data, the preliminary designation will in practice probably be based on indirect criteria (e.g. changes in water levels or flows that are critical for biota). To develop criteria for heavily modified lakes, the REGCEL analysis was applied in 50 lakes with a natural water level fluctuation and 50 lakes with regulated water level (e.g. Hellsten *et al.* 2002). With the aid of these methods the whole set of Finnish lakes were divided into three different groups based on water level fluctuation: natural lakes, lakes which are probably heavily modified and heavily modified lakes.

In the Finnish case study the most heavily regulated lake of Finland, Lake Kemijärvi was chosen with the idea that most of the harmful effects are obviously visible in a lake with such heavy regulation. The lake can be divided into a main lake area with maximum water level regulation and several smaller sub-basins with milder regulation.

Although the focus of the case study is the designation process of Lake Kemijärvi, the pressures of human activities on the River Raudanjoki, a large tributary reaching the River Kemijoki 70 km below Lake Kemijärvi, have also been identified (Fig. 1). The River Raudanjoki consists of one free-flowing part affected by a hydropower plant, one regulated Lake Olkkajärvi and a natural river with small lakes upstream of the lake. As a separate sub-study, water body identification was also applied to the main stream of the River Kemijoki between Lake Kemijärvi and Bothnian Bay. In this report, we present the main results of the Lake Kemijärvi case study, but conclusions and lessons learned refer to both these sub-studies.

3.2 General Remarks

Lake Kemijärvi (128-285 km^2) is the largest lake of the River Kemijoki watercourse, which is the longest river in Finland (Fig. 1). Water level regulation started in 1965 with a maximal amplitude of 7 metres, which is the largest regulation amplitude in Finnish lakes. At the beginning of regulation, the summer water level was raised by two metres compared to the original summer water level. The main objectives of regulation are hydropower production and flood protection. The regulation has caused major harmful impacts on nature, e.g. the area of littoral vegetation and zoobenthos biomass have decreased, several species have disappeared and the living conditions of fish stocks have degraded.

The HMWB-project has been carried out in close co-operation with the regulation development project of Lake Kemijärvi, which also started in 2000. The aim of this project is to assess the needs and possibilities to alleviate the harmful impacts of regulation. The steering group of the HMWB-project was established in September 2000 consisting of representatives of environment and fishery authorities, the City of Kemijärvi and the hydropower company Kemijoki Ltd. The preliminary results of this case study have been presented and discussed in several meetings and workshops in Finland.

The Lake Kemijärvi case study is a part of the HMWB hydropower sub-group headed by Austria. The project is linked with the large study, which aims to discriminate Finnish regulated lakes based on water level fluctuation and biological characteristics. The project is also a part of the LUOMUJOKI research project (Kerätär 2003).

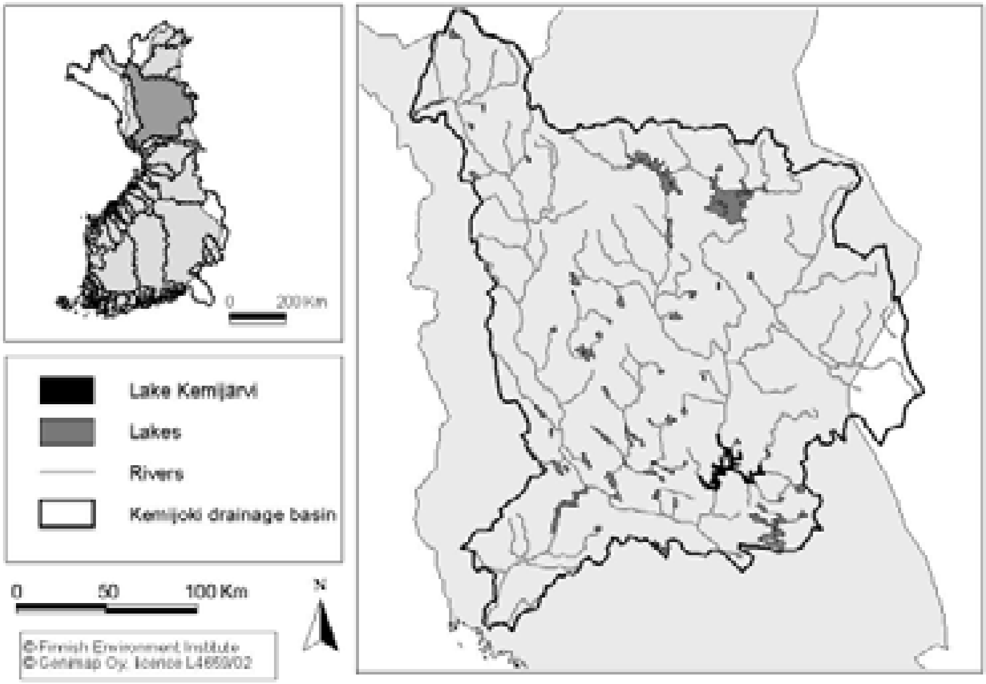

Fig. 1. The River Kemijoki system in northern Finland with Lake Kemijärvi and the River Raudanjoki.

Description of the Case Study Area

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4.1 Geology, Topography and Hydrology

The catchment of River Kemijoki (51 127 km^2) consists of granites and gneisses, which are covered by till formation. The area above Lake Kemijärvi is relatively low ranging from 150 metre up to 250 metre above sea level. The catchment area (25 792 km^2) is largely situated below an elevation of 300 metres above sea level. The total length of the River Kemijoki is 475 km, of which 175 km is situated above Lake Kemijärvi (Fig. 1). The catchment area has a low lake percentage of 4.7 %, and consists mainly of forests (46.7 %), peatlands (40 %) and other land types (20.1 %), whereas the field area is only 0.5 % (Kauppila & Pitkänen 1995).

Lake Kemijärvi is a large lake with an area ranging from 128 to 285 km^3 depending on the water level. Its mean depth varies between 1.7 and 4.5 metre. The total volume is between 200 – 1300 milj.m^3 with a mean discharge of 311 m^3/s. Residence time varies between 8 to 52 days.

The River Kemijoki is divided into three different tributaries above Lake Kemijärvi near the municipal centre of Pelkosenniemi (Fig. 1). The easternmost tributary River Ylä-Kemijoki (length 149 km) has a relatively undisturbed catchment area with the planned Vuotos reservoir. The middle tributary River Luirojoki (length 133 km) runs from Reservoir Lokka (417 km^2, built 1967), which has dammed the original river with only of 6-7 m^3/s remaining flow. The westernmost tributary is the River Kitinen (length 155 km), which consist of stairs of hydropower plants running from Reservoir Porttipahta (214 km^2, built 1970). Since 1981 the waters from reservoir Lokka run via the channel of Vuotso to Porttipahta. The River Kitinen is under water level regulation, also partly used for short time regulation. The River Jumiskonjoki (length 100 km) runs from the eastern branch of Lake Kemijärvi and is fully developed including several regulated lakes, river diversions and one power plant. The River Kemijoki downstream from Lake Kemijärvi is almost fully developed consisting of 8 different power plants and run-off-river impoundments. There is only one relatively natural stretch between the power plants Vanttaus- and Valajaskoski, but it is also affected by short-term regulation.

The hydrology of Lake Kemijärvi is characterized by a strong spring flood, which was higher than two metres in its natural state with a discharge peak of more than 1800 m^3/s (Fig. 2). Water level regulation has cut off the spring flood by lowering the water level during winter, which has lead to higher winter discharges for hydropower production. On the other hand the summer time water level is raised due to higher storage capacity. Despite high storage capacity only a small part of the spring flood can be stored in the lake and high flow still exists at the lower River Kemijoki causing increased flood risks.

4.2 Socio-economic Geography and Human Activities in the Catchment

The total population of the whole Kemijoki catchment is only about 100 000 inhabitants of which 25 000 are located above Lake Kemijärvi. The Kemijoki catchment covers largely the whole county of Lapland. The population density is only 1 inhabitant per km^2. The largest city is the city of Kemijärvi, which is situated in the northern part of the lake. Other population centres are such as Pelkosenniemi, Savukoski and Sodankylä.

The human activities of the drainage area consist of forestry and small-scale farming with reindeer husbandry. All these activities cause diffuse pollution and can also change hydrological properties of catchment. Industrial activities are mainly affected by a wood pulp mill situated in the City of Kemijärvi. Other point source pollution is caused by the municipal wastewater of the city, the tourist attraction of Suomutunturi and some fish farms.

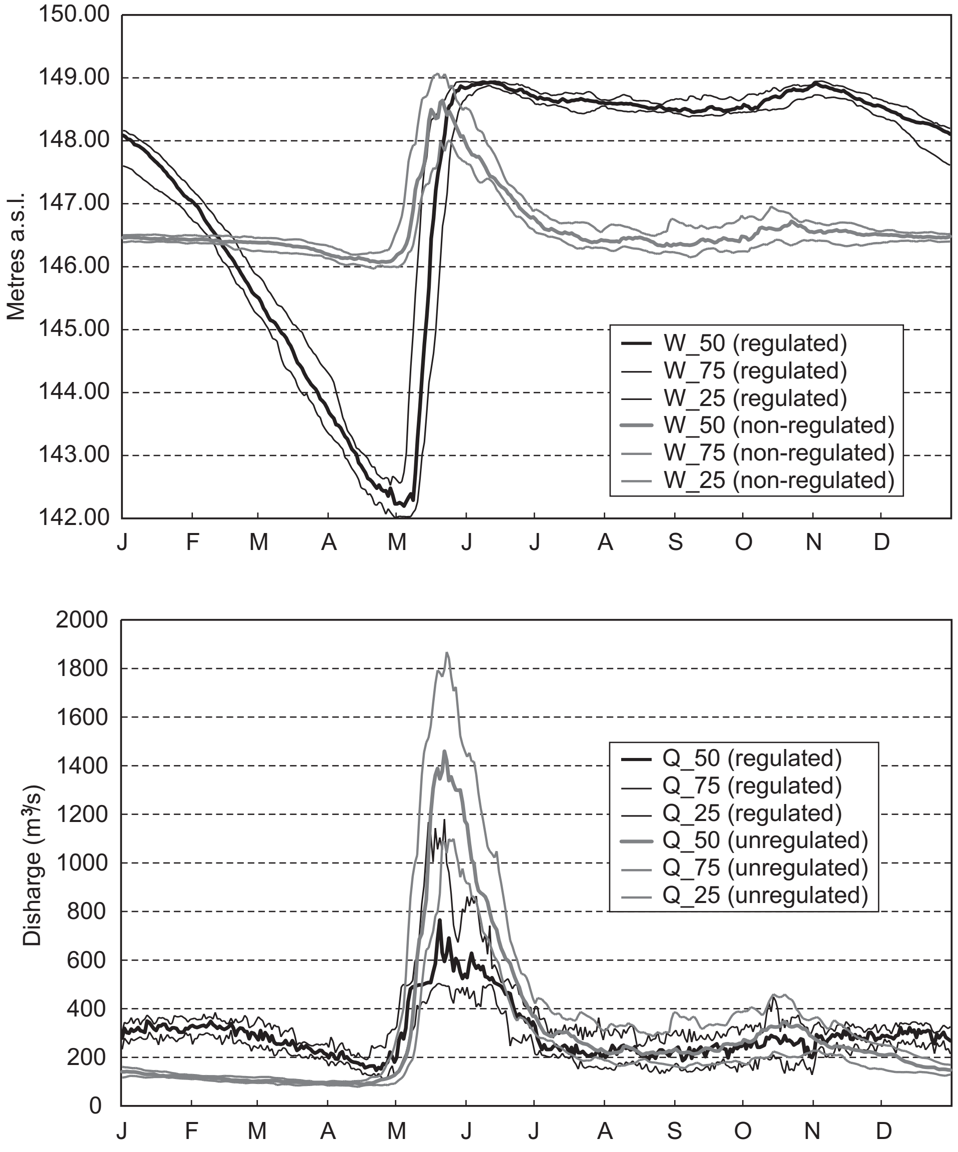


Fig. 2. Water level fluctuation (upper panel) and outflow (lower panel) of L. Kemijärvi before and after (re-calculated values) regulation (years 1980-99).

Hydropower production is the most important human activity of the catchment area. The whole uppermost catchment area except the River Ylä-Kemijoki is fully developed for hydropower production, which means reduced flow in River Luirojoki and a set of run-of-river impoundments in the River Kitinen as explained in previous chapters.

4.3 Identification of Water Bodies

The River Kemijoki belongs to the ecoregion of the Fenno-Scandian shield. According to A-type typology Lake Kemijärvi is part of lowland, depth varies between 3 to 15 m, size is more than 100 km^2 and geology is siliceus. However, the peat land coverage of the drainage area is more than 40 % and therefore it can be classified as organic too.

Lake Kemijärvi can be divided into a main lake area with maximum water level regulation and several smaller sub-basins with milder regulation due to constructions of submerged weirs (Fig. 3). These sub-basins, which form 43.3 % of the total lake area, are:

- Upper part of the lake (area 82 km^2, max. regulation range 3.25 m)
- Hietaselkä sub-basin (area 22.7 km^2, max. regulation range 5 m)
- Lautalahti-Reinikanperä sub-basin (area 8 km^2, max. regulation range 3.25 m)
- Lantunki sub-basin (area 1.7 km^2, max. regulation range 4 m)
- Kaisanlahti sub-basin (area 9.1 km^2, max. regulation range 3.5 m)

In addition to the main lake there are several smaller lakes, which were before water level regulation part of the lake at least during the spring flood (Table 2, Fig. 3). After water level rise and constructions of embankments, these small lakes are restricted and their water levels are regulated by high capacity pumps.

In spite of sub-basins with lesser regulation amplitude than the whole, Lake Kemijärvi can be seen as **one water body** from outlet Seitakorva up to Pelkosenniemi. Small lakes such as Pöyliöjärvi (2.57 km^2), Kostamojärvi (1.05 km^2), Karsimusjärvi (0.42 km^2), Porolampi (0.05 km^2), Severijärvi (3.00 km^2) and Luusuanjärvi (1.8 km^2) are permanently detached from the main lake. There is also one small Lake Sorsajärvi, which was before the regulation a separate lake delineated from the main lake by a riverbank. Due to dredging of the outlet for timber floating, it is now a part of the main lake and drained during late spring. In these detached lakes regulation practices and problems deviate significantly from Lake Kemijärvi. Main problems are related to water quality due to long residence time and diffusive loading.

Table 2. Lake Kemijärvi with different sub-basins. See Fig. 3 for details.

Name of the group	Main pressures to the group	Main physical alterations of the group	Water bodies to the group
Lake Kemijärvi	Hydropower, flood protection	Dams, disruption of river continuum, embankments	Lake Kemijärvi
Detached lakes	Flood protection, (hydropower)	Embankments	Lake Pöyliöjärvi Lake Kostamojärvi Lake Karsimusjärvi Lake Porolampi Lake Severijärvi Lake Luusuanjärvi

In the sub-case of the River Raudanjoki, the channel can be divided into four different stretches. These include one free-flowing part below Lake Jyrhämäjärvi, one channel between Lakes Jyrhämäjärvi and Olkkajärvi affected by a hydropower plant, one quite natural stretch between Lakes Olkkajärvi and Vikajärvi and a natural river upstream of Lake Vikajärvi (Fig. 4). In addition to these stretches there are Lakes Jyrhämäjärvi, Olkkajärvi and Vikajärvi.

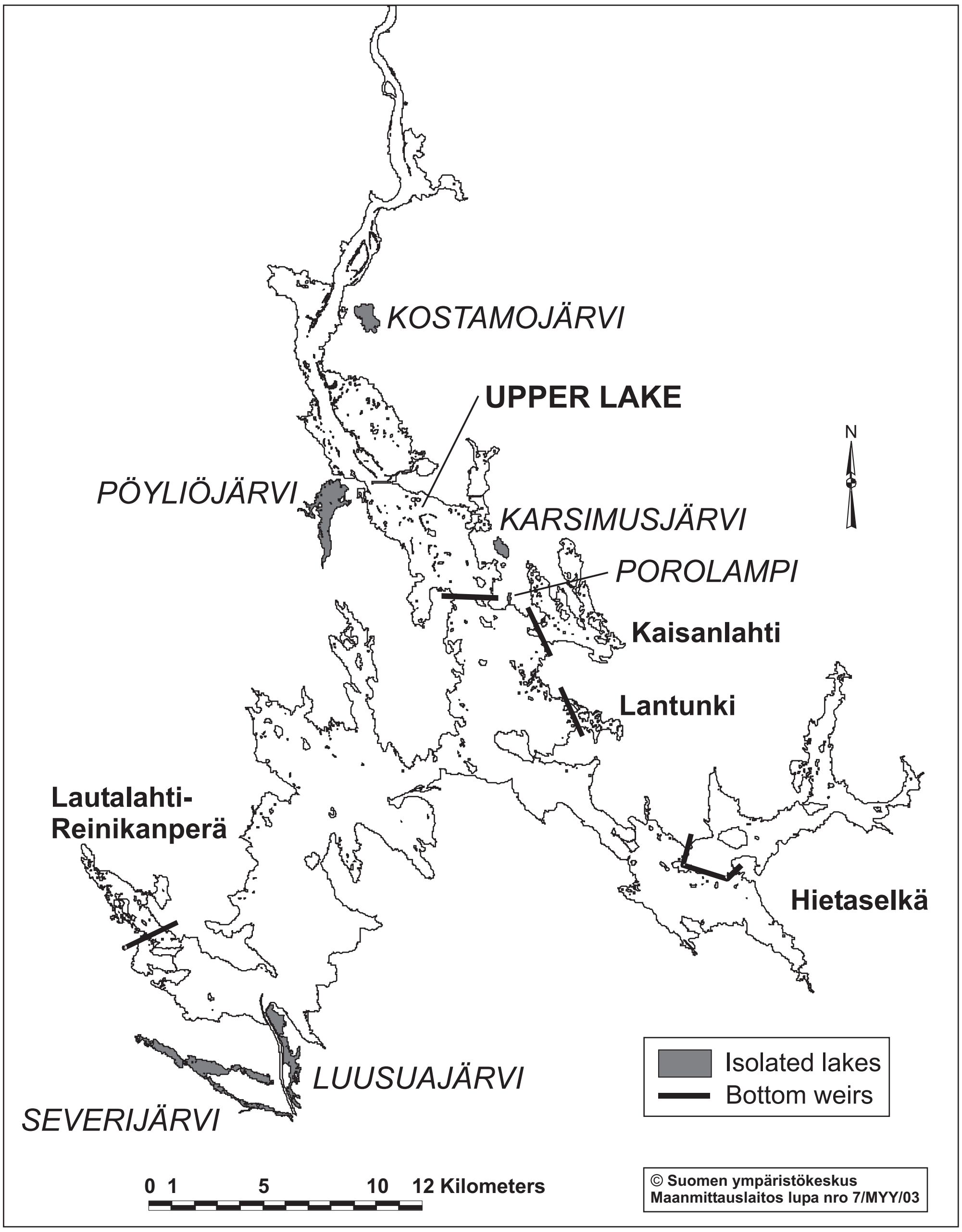


Fig. 3. Lake Kemijärvi and other water bodies (marked by blue). Bottom weirs or natural thresholds marked by red lines.

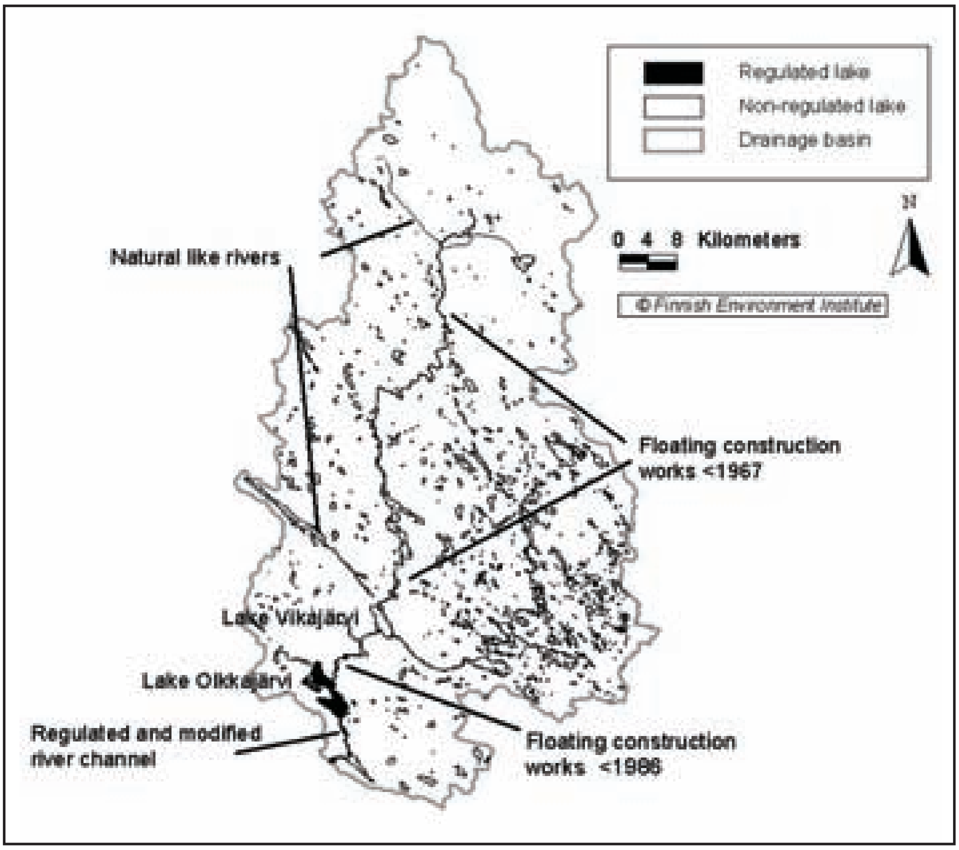


Fig. 4. Main water bodies in the River Raudanjoki sub-study area.

4.4 Discussion and Conclusions

The ultimate goal of the identification of a water body should be to create reasonable management units. In practice this means that the size of the water body should be reasonable for the purpose of water protection, planning of water use and restoration methods. The identification of a water body is from our point of view a very important phase because it has far-reaching impacts for the implementation of WFD and more or less defines the scale and amount of forthcoming work. The identification of a water body can affect the number of water bodies that have to be discriminated and classified, the number of heavily modified water bodies and monitoring programs. The identification of a water body can be seen as an iterative process, which is affected by the discrimination of water body types, designation process and perhaps the results of classification.

According to WFD (Annex II) the identification of water bodies in lake systems is more straightforward than in river systems, because the main principle is that one lake is one water body and a river can be divided into many water bodies. In our case study we analysed the questions related to identification of rivers in the main stream of the River Kemijoki. The main stream of the River Kemijoki originates from Lake Kemijärvi and flows to the Gulf of Bothnia (Fig. 5). The length of the river is ca 220 km and there are 8 power plants and 7 run-of-river impoundments. However, the ca 70 km long middle part of the river between Valajaskoski and Vanttauskoski power plants resembles the natural River Kemijoki. We consider three main identification alternatives (Fig. 5).

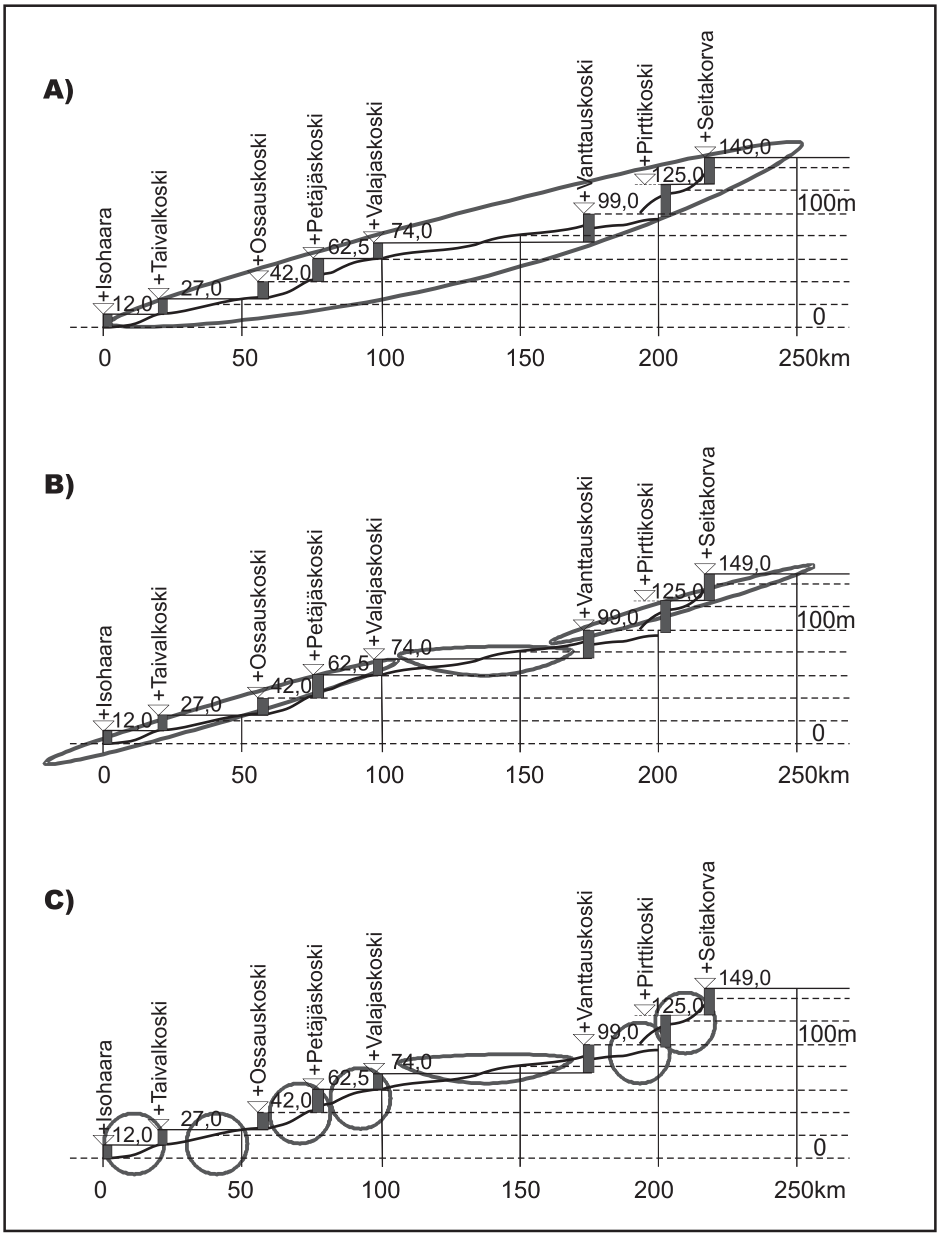


Fig. 5. The River Kemijoki below Lake Kemijärvi and three identification alternatives. Refer to the text for details.

Main stream of River Kemijoki is

- A. One heavily modified water body
- B. Two water bodies: heavily modified and natural (non-constructed part)
- C. Seven water bodies: all run-of-river impoundment and the non-constructed part are separate water bodies

The following questions were scrutinized:

Are run-of-river impoundments separate water bodies?

- YES: Regulation pattern and problems are different.
- NO: They belong to the same river type.

- NO: It is not reasonable to define Maximum (MEP) and Good Ecological Potential (GEP) separately for each impoundment, which is needed in the case of separate water bodies.
- NO: Holistic approach is more reasonable because power plants are used operationally as one unit and finding cost-effective mitigation measures may require a wider point of view.

⇒ CONCLUSION: NO

Is a non-constructed part of the river a natural water body?

- YES: Some habitats (e.g. shore meadows, erosion banks) typical for the natural River Kemijoki still exist
- NO: According to flow analysis, short-time regulation has changed the hydrological regime significantly. The remaining natural part represents only a small fraction of the main channel.
- YES/NO: Changes in fish fauna due to the power plants.
- Only one fish ladder exists in the River Kemijoki (at the lowest power plant)
- Possibility to apply less stringent objectives

⇒ CONCLUSION: NO or More information needed of the current status of river.

Compared to the River Kemijoki the identification of water body in Lake Kemijärvi was a much easier process. However, the demarcation of the upstream border of Lake Kemijärvi was difficult due to the raised water level, while the downstream border was clearly formed by the power plant dam. Before the regulation several isolated lakes of the area were connected to Lake Kemijärvi only during the spring floods. We decided to consider these lakes as separate water bodies. Still, a question remains whether or not to separate some bays and the upper proportion of the lake having different water level fluctuation regimes due to the bottom weirs. However, since their ecological status appears identical, we decided to include these parts into the same water body.

5

Physical Alterations

5.1 Pressures and Uses

The power plants downstream have permanently closed the migrating routes of salmon, sea trout and anadromous whitefish (Table 3). On the other hand, constructions upstream have limited the routes of migratory whitefish to the River Kitinen. Construction of the large Lokka and Porttipahta reservoirs have also caused the loading of nutrients and mercury into Lake Kemijärvi (Virtanen *et al.* 1993). There was a quite significant increase in the mercury content of sediment during the first years of regulation, which was related to erosion launched out by raised water level or reservoirs upstream (Kinnunen 1989, Meriläinen *et al.* 1994).

The main pressures on Lake Kemijärvi are related to water level regulation aiming at increasing hydropower production and decreasing flood damage both in Lake Kemijärvi and in the River Kemijoki downstream (Table 3). Hydrological alterations, including the raised water level during the beginning of regulation (1965) and the annual winter draw-down by 7 metres, have caused considerable ecological deterioration of the lake. The main impacts include heavy erosion, degradation of littoral vegetation and changes in benthic fauna and fish stocks. According to paleolimnological analysis a clear increase in erosion can be noticed from the organic content of sediment (Meriläinen *et al.* 1994). On the other hand, the water quality during the winter has been improved due to decreased residence time and increased flow from reservoirs (Virtanen *et al.* 1993). Water level lowering causes oxygen depletion in some isolated bays during late winter due to isolation from the main lake. Water quality problems in the isolated small lakes are much more serious, and some of them are artificially oxygenated during the ice covered period. The impacts of morphological changes in Lake Kemijärvi are relatively limited, although the alterations have been exceptionally extensive compared to other regulated lakes in Finland. The hydrological and morphological alterations are described in detail in chapters 5.2 and 5.3.

Nutrient loading consists of point source pollution (pulp mill and wastewater from the City of Kemijärvi), non-point source pollution (forestry, agriculture) and loading from large reservoirs upstream (Table 3). The drainage basin is largely in a natural state and natural background loading plays an important role in Lake Kemijärvi. Kauppila & Pitkänen (1995) estimated that about 70 – 90 % of the load originates from the drainage area. However, they did not extract the effect of upstream reservoirs, which have completely changed the annual balance (Hellsten *et al.* 1993). Before reservoirs, most of the loading took place during the spring flood. Due to the winter draw-down of reservoirs, the major proportion of loading occurs during winter. Nowadays the spring flood (May-June) contributes 38 – 46 % of the nutrients (Kauppila & Pitkänen 1995). The share of diffuse loading, originating mainly from agriculture, is only 4 % of the total load. Eutrophication caused by point source pollution is more significant than expected, since during the late summer more than 52 % of bioavailable phosphorous and 38 % of nitrogen originates from industrial and municipal wastewater and fish farms (Kauppila & Pitkänen 1995) However, due to short resident time hardly any water quality problems occur and only 6 % of loading is sedimented to the lake (Virtanen *et al.* 1993).

Table 3. Human impacts on the status of Lake Kemijärvi.

Factors	Water levels	Geomorphology	Sediment quality	Water quality	Phytoplankton	Benthic fauna	Littoral vegetation	Fishes
Water construction								
* Dikes, dams etc.	**	+	0	- (weirs)	0	+ (weirs)	-	-
* Construction downstream	0	0	0	0	0	0	0	- - - 1)
* Construction upstream	***	0	- (mercury)	+(oxygen), - (humus, nutrients)	- (eutrophication)?	0 (changed divers.)	0	- - 2)
Regulation	***	- - -	0, - (eroded sand)	+ (winter), 0 (summer)	0	- - -	- - - (changed divers.) 3)	- -
Point source pollution	0	0	- - (chlorophenoles)	- -	- - (eutrophiccation)	-	0	-
Diffuse pollution	0	0	0	-	-	0	0	0
Fishery	0	0	0	0	0	0	0	+/0
Fish stocking	0	0	0	0	0	0	0	++
Log floating	0	0	- (wood litter)	0	0	0	0	0/- - 4)

0 = no changes, - = slight negative impact, - - = moderate negative impact, - - - = great negative impact,
+ = insignificant positive impact, ++ = moderate positive impact, + + + = great positive impact,
* slight positive impact, ** moderate positive impact, *** great positive impact,
1) Three lost species, 2) One lost species, one new species (+ or - ?), 3) Eight lost species, 4) Significant changes at tributaries.

In addition to eutrophication, some other harmful effects are related to the pulp mill industry. Clear evidence exists of the decreased fecundity of burbot (*Lota lota*) in Kemijärvi as compared to reference areas (Korhonen 2000). Some residues of chlorophenoles are also found in sediments.

Intensive fishery and compensative fish stocking in particular significantly affect the ecological status of the lake. Large amounts of whitefish (*Coregonus albula*), brown trout (*Salmo trutta*) and northern pike (*Esox lucius*) are stocked annually into the lake. While the productivity of the lake has been reduced, the stocking activities have caused overstocking and consequently a size decrease of whitefish (Kerätär *et al.* 2003).

Other significant pressures include intensive dredging actions and other channel modifications related to log floating in the tributaries. In the whole River Kemijoki area log floating ended in 1992. However, there are still remnants of wood debris and other material on shore areas. Most of the areas used for timber floating have already been cleaned. Nowadays, some parts of the lake have quite extensive cottage developments along the shore and there are hundreds of recreational users and fishermen.

5.2 Physical Alterations

Physical alterations are typical for a watercourse used for hydropower production and combined flood protection. It has changed the river profile and disrupted river continuum with power plant dams (Fig. 5). The largest physical changes consist of the embankments separating the original flood plain from the main river, and the concrete dam of the power station. The concrete dam near the outlet of Kemijärvi (Seitakorva) reaches a total length of 158 m and height of 24.5 m. Other embankments are 3.3 km long with the height of 19 m. In the southern part of the lake a total of 15.7 km of embankments exist (h=3.2 m) and in the northern part a total of 12.0 km (h=3.8 m). Embankments have separated parts of the former flood plain from the main river. As a result some small lakes are permanently detached from the main lake. The total amount of embankments makes up 3.7 % of the total shoreline of lake (851 km).

Other physical changes are related to bank reinforcement for erosion protection – during the period 1965-1998 more than 41.4 kilometres of the shoreline (4.9 %) has been protected by rip-rap revetments. Although acting as main mitigation measures to reduce harmful impacts of erosion, these treatments permanently change the nature of the shoreline.

In addition, a 7.3 km channel was dredged into the lake in order to enable water level draw down by 7 m during the late winter. The dredging removed approximately 1.3 milj.m^3 of bottom material to submerged places or places above water level.

Other impacts are related to the low flow or limited turn over of water in isolated lakes as well as an artificial discharge regime downstream from the outlet (see details in the next chapter). Turbines also directly damage fishes.

5.3 Changes in the Hydromorphological Characteristics of the Water Bodies and Assessment of Resulting Impacts

The regulation has dramatically altered water levels in Lake Kemijärvi (Fig. 2). The changes in water levels and their impacts on ecology and recreational use were analysed applying the REGCEL spreadsheet. Analysis consisted of the following phases:

- Determination of regulated and non-regulated (re-calculated values) daily water levels from 1980 to 1999.
- Identifying the indicators describing the effects of water level fluctuation on the littoral environment, fish, birds and recreational use.
- Identifying the most critical water level changes affecting the status and use of water course.

The indicators applied in this study are presented in Table 4. The choice of indicators was based on earlier studies on regulated lakes in Northern Finland (Hellsten *et al.* 1996, Hellsten 2000, Marttunen *et al.* 2001, Hellsten *et al.* 2002). The chosen indicators describe the effects on littoral vegetation (Hellsten 1997, Hellsten 2001), littoral biomass of benthic fauna (Palomäki 1993) and spawning success of fish (whitefish, northern pike).

The indicators can be divided into general and specific ones (Table 4). General indicators of regulation were annual water level fluctuation (A), water level fluctuation during the summer (G) and water level decrease during the ice-covered period (B). These indicators give a rough idea of water level fluctuation and its impacts (Hellsten *et al.* 1996). The specific indicators depict the impacts of regulation on e.g. frost and ice sensitive macrophytes and zoobenthos species (J-K) and the reproduction of pike (H).

Lake Kemijärvi is the most heavily regulated lake in Finland. Maximum regulation amplitude is 7 metres and the whole regulation amplitude is used every year. In this respect Lake Kemijärvi deviates from other Finnish regulated lakes where the regulation amplitude is not totally utilised. The main reason for total use of storage capacity is the large volume of the spring flood compared to the volume of Lake Kemijärvi due to the large drainage area with a small lake percentage.

Table 4. Main indicators and calculation principles in REGCEL analysis.

Indicator	Calculation principle
A. Annual water level fluctuation (m)	MHW – MNW
B. Water level decrease during ice-covered period (m)	W_IN – NW_ICP
C. Magnitude of spring flood (m)	MHW_(IO –2 week – IO +4 week) – MW_50_OWP
D. Number of days from ice-off to maximum water level in spring (n)	HW_(IO –2 week – IO +4 week) - W_IO
E. Percentage of springs with low water level (%)	Years when, (W_75_OWP – W_IO > 0) / number of years * 100
F. Water level rhythm during growing season (m)	HW_(IO –2 week – IO +4 week) – NW_(1.6.-30.9)
G. Water level fluctuation during the summer (June-August) (m)	HW_(1.6.-30.8.) – NW_ (1.6.-30.8.)
H. Minimum water depth in *Carex* belt during spawning of northern pike (m)	NW_(IO – IO +1 month) – W-_75_OWP
I. Maximum vertical extension of *Carex* belt (m)	W_10_OWP – W_75_OWP
J. Percentage of frozen productive zone (%)	(W_50_growing season – W_6.2.) + (0,9 * ice thickness) / depth of productive zone * 100
K. Percentage of disturbed productive zone (%)	(MHW – MNW) / depth of the productive zone * 100
L. Water level during open-water period	W_50_OWP

OWP = Open-water period, ICP = Ice-covered period, IO = Ice-off date, IN = ice-on date.

Annual water level fluctuation (A) is more than doubled by the regulation and is significantly more than in other regulated or non-regulated lakes in northern Finland (Table 5). It should be noted that the annual range was also exceptionally wide in its natural state. Water level fluctuation during the summer is nowadays much less than in the natural state, which has on one hand improved the recreational use of shores but on the other hand caused a narrower littoral vegetation zone.

The biggest change is the water level decrease during the ice-covered period (B); the present value (6.75 m) is 12-fold compared to the natural one (0.55 m) (Table 5). As a result large areas are under ice exposure during winter, which affects the reproduction success of whitefish. Generally, the maximum amount of whitefish eggs are found at a depth of 0.5-2 m, which indicates high sensitivity to a water level decrease during winter (Valkeajärvi 2001). It is quite evident that in the current situation the reproduction of lake-spawning whitefish is impossible and also eggs of vendace (*Coregonus albula*) are largely destroyed under the down-dwelling ice. However, there is still a relatively abundant vendace stock, which proves that a significant part of the eggs survive due to deeper spawning grounds (Tikkanen & Hellsten 1987).

Regulation has raised the summer water level (L) by 2.05 metres compared to the recalculated natural value (Table 5). As shown in several other studies (e.g. Hellsten 1997), such a rise has launched heavy geomorphological changes at the sandy shores of lake. In its natural state in Finnish conditions the exceptionally high spring flood stimulated some erosion as noted in the pre-regulation study of Hydroconsult (1964). Flood tolerant shore forests were also inundated in the beginning of regulation and in spite of restoration works there are still quite many remnants of terrestrial vegetation.

Table 5. Indicator values of Lake Kemijärvi in its natural and regulated state (years 1980-99).

Indicator	Natural state	Regulated state
A. Annual water level fluctuation (m)	3.19	6.96
B. Water level decrease during ice-covered period (m)	0.55	6.75
C. Magnitude of spring flood (m)	2.51	0.32
D. Number of days from ice-off to maximum water level in spring (n)	4	21
E. Percentage of springs with low water level (%)	0	80
F. Water level rhythm during growing season (m)	1.05	-0.32
G. Water level fluctuation during the summer (June-August) (m)	0.99	0.39
H. Minimum water depth in *Carex* belt during spawning of northern pike (m)	0.73	-1.49
I. Maximum vertical extension of *Carex* belt (m)	1.66	0.37
J. Percentage of frozen productive zone (%)	46	132
K. Percentage of disturbed productive zone (%)	82	179
L. Water level during open water period (m asl)	146.62	148.67

The relationship between water level fluctuation and littoral vegetation is well known and therefore several different indicators are used. Growth areas of *Carex*-species (sedges) are directly related to water level fluctuations (Table 4). A high spring flood with a lowering water level towards summer has a favourable effect on their spread (Vaarama 1938, Maristo 1941). A high flood prevents competition from shrubs, grasses and mosses, since sedges can endure relatively long periods of submersion in a state of dormancy (e.g. Elveland 1984). Maximum vertical extension of the *Carex*-zone (I) is calculated as a difference between the duration of 10% and 75% for open-water periods (Hellsten *et al.* 1997, Nykänen 1998, Hellsten 2002). The *Carex*-zone (I) was more than five fold in the natural state compared to the present situation (Table 5). However, the width of the zone is still quite wide compared to other Finnish non-regulated and regulated lakes.

Typically, in many Finnish regulated lakes the water level rises during the summer, whereas in non-regulated lakes it decreases after the spring flood. A littoral ecosystem has adapted to the decreasing water level and therefore opposite development harms the formation of a littoral zone. The phenomenon is described by water level rhythm (F) and magnitude of spring flood (C) (Table 4). The decreasing rhythm was very clear in the non-regulated Lake Kemijärvi, where the water level was lowering by more than one metre (Table 5). Regulation has changed this rhythm. Due to decreasing rhythm conditions, vegetation has deteriorated significantly.

Large isoetids such as *Isoetes lacustris* and *Lobelia dortmanna* are sensitive to freezing and lack of light (Rørslett 1984, Hellsten 2001, 2002). Their distribution range can be predicted as a share (%) of the frozen productive zone (J) (Table 4, Hellsten 1997). In the natural situation half of the littoral was unfrozen and Isoetes lacustris was found in the lake (Table 5, Hellsten *et al.* 1999, Hellsten 2002). In the present situation the whole littoral is frozen and *Isoetes lacustris* has disappeared and been partly replaced by the more tolerant *Isoetes echinospora* (Hellsten 2002).

Effects of water level fluctuation on littoral benthic fauna are estimated according to Palomäki (1993) by the percentage of the disturbed water level fluctuation zone of the calculated productive zone (K) (Table 4). This indicator also gives a rough estimate of the available food resources of benthos-eating fish. The share of the disturbed littoral is three times more compared to a natural situation, which shows significant changes in littoral biota (Table 5).

Reproduction of spring-spawning fishes such as northern pike is described by minimum water levels in the *Carex*-zone during the spawning period, predicted as four weeks from ice-off (H) (Table 4). The *Carex*-zone represents the best available area for reproduction carrying out several times more young fries as in other vegetation zones (Korhonen 1999). In the natural state there was almost a half metre of water in the *Carex* zone whereas in the present situation the whole zone is dry (Table 5). It should be noted that this indicator is very sensitive to errors in Lake Kemijärvi where the water level raises over 30 cm/day in May and timing of spawning is a critical factor. For example, five days difference in spawning time means 1.5 metres rise in water levels and completely different results.

The impacts on recreational use are described by the water level decrease during the ice-covered period (B), water levels after the ice-off date (D,E) and fluctuation of summer water levels (G) (Table 4). Due to the decreasing water level during winter, the winter fishing by gillnets and use of snowmobiles has become more difficult (Table 5). After the ice-off water level rises rapidly, but it is at too low a level for recreational use during the two week period after ice-off. During the summer time water levels are more appropriate for the recreational use of shores than in the natural state. There are no floods anymore and the fluctuation in summer water levels is diminished.

The substudy of the River Raudanjoki addressed changes in river morphology as well as in hydrology caused by dredging for timber floating and hydropower production (Table 6). River continuity is also broken by bottom weir and the power plant dam. On the other hand, extensive channel restorations have been conducted during recent decades. General impacts of these changes are explained in Table 6.

Table 6. Physical pressures occurring in the River Raudanjoki and introductory estimation of their impacts in different sectors of the river.

	Stream length	Kemijoki – Jyrhämäjärvi 3 km	Jyrhämäjärvi – Olkkajärvi 2.2 km	Olkkajärvi – Vikajärvi 11 km	Vikajärvi – Upper course > 94 km
Physical pressures	**Impact**				
Dams (in the River Kemijoki)	Disruption of the river continuum in the Kemijoki drainage basin	DE	DE	DE	DE
Dam (Permantokoski in the River Raudanjoki)	Disruption of the sediment transport and passage of organisms between Rivers Kemijoki and Raudanjoki	0	- -	- -	DE
Regulation	Changes in water levels and discharge	0	- -	0	0
Submerged weir	Changes in water levels and discharge	DE	0	0	0
Channel modification	Changes in discharge in the old channel, new artificial channel	0	- - (90 % of the channel)	0	0
Floating construction works	Changes in water levels, discharge and channel morphology	-	0	- -	-
Embankments / floating structures	Changes in the littoral	-	- -	-	-
Restorations	Restorations of rapids cause changes in water levels, discharge and channel morphology	DE (< 10 % of the channel)	0	DE (~25 % of the channel)	DE (< 20 % of the channel)

0 no impact, - minor negative impact, - - distinguished negative impact, DE difficult to estimate.

5.4 Discussion and Conclusions

In the Working Group paper five suggested that for the purpose of the case studies the following scale for the investigations will be applied:

- 1 km or area greater than 1 km^2 (rivers with catchment < 1000 km^2)
- 10 km or area greater than 10 km^2 (rivers with catchment > 1000 km^2)

Our experiences with the River Raudanjoki substudy suggest that this scale should be flexible. In rivers where major changes due to anthropogenic pressures have occurred, the approach should be more detailed compared to rivers with no or minor pressures. For instance, in sparsely populated Lapland large areas are without any significant signs of human impact.

Especially from the River Raudanjoki it was very difficult to gather data from the morphological changes and current status. Most of the dredging work has taken place during the fifties without accurate planning. The same regards the river engineering works in other parts of Finland. There are no synthesis or databases of the morphological alterations in Finnish rivers. The data must be gathered from old documents and plans, which makes the work very laborious. Another problem in the River Raudanjoki study was the estimation of the impacts of large restoration works, which were carried out after the end of timber floating in the beginning of the seventies. It was impossible to estimate how much restoration work has affected river status and what is the degree of recovery due to lack of data on the morphological status of the river. Consequently, there is a clear need to develop methods to assess the structural status of rivers.

A major problem is the poor knowledge of the location, quantity and quality of physical alterations of stream channels in Finland. However, it is well known that physical alterations of headwater stream channels induced by forestry activities concern a vast majority of our streams. Nevertheless, these alterations probably seldom result in the designation of streams as heavily modified. This is because the alterations and their ecological implications are highly variable and repairable or largely dependent on the interplay with other pressures. This points out the need for integrated, multi-pressure impact assessment focusing on areas with indications of large scale catchment alterations.

Assessing the effects of the hydrological alterations of Lake Kemijärvi were based on REGCEL-water level analysis, which is the main tool in assessing the impacts of water level regulation in Finnish lakes. Probably the provisional designation of regulated lakes in Finland will be based on that method. The current water analysis tool for regulated lakes will be further developed by testing the relationships between biological and hydrological parameters in 2002.

6

Ecological Status

6.1 Biological Quality Elements

The Water Framework Directive (WFD Annex V, 1.1 "Quality elements for the Classification of Ecological Status) requires that the composition and abundance of phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna, and fish fauna are used as biological elements for the ecological status of lakes. The definition of the ecological status of Lake Kemijärvi was based on all the above mentioned biological quality elements except phytoplankton and phytobenthos. We decided to use littoral macrozoobenthos, because there was relatively good data of it (Tikkanen 1987). The ranking of different ecological status classes is based on our expert judgement due to lack of national ecological classification system for Finnish lakes. It should be noted, that REGCEL water level analysis was only used in assessing changes in the hydromorphological characteristics and resulting impacts as well as provisional designation procedure whereas ecological status is based on direct observations (Table 7).

Table 7. Preliminary threshold values for biological quality elements.

Biological quality element	Ecological status			Reference lake	Lake Kemijärvi			
	Moderate	Good	High	Value	Nat. value	Pres. value	EQR	Ranking
Macrophytes								
Number of species (n)	30	40	50		46	37	0.80	High
Area of flooded *Carex* vegetation (ha)	-	-	-		179	14	0.08	< Moderate
Vertical extension of *Carex* zone (m)	0.4	0.6	0.8		0.85 (3.04)$^{1)}$	0.45 (1.01)$^{1)}$	0.30-0.53	Moderate
Presence of frost sensitive isoetids (n)	1	2	3		2	1	0.50?	Moderate
Macrozoobenthos								
Number of typical taxons (n)	>15	>22	>29	35.9	-	35	0.97	High
Number of typical	>9	>13	>17	20.6	-	19	0.92	High
Number of taxons (n) taxonomical groups (n)	>19	>29	>38	47.14	-	42	0.89	High
Presence of frost sensitive species (n)	1	2	3		3	2	0.67	Good/Moderate
Fish fauna								
Number of species (n)	14	16	18	18	15-22	18	1.00?	High
Presence of migratory species	no	yes$^{2)}$	yes$^{3)}$		yes	no$^{4)}$	-	Moderate

EQR = Ecological Quality Ratio, $^{1)}$maximum values in parenthesis, $^{2)}$migration possible to tributary, $^{3)}$migration possible from sea, $^{4)}$anadromous species. Reference lake represents average values of littoral species from ten Finnish lakes.

6.1.1 Macrophytes

Macrophytes are a suitable element for assessment of the ecological status of regulated lakes, because they are sensitive against water level fluctuation (e.g. Rørslett 1989, Hellsten 2001). The effects of water level regulation on lake littoral in northern regions have been extensively studied during the last decades (Sundborg 1977, Nilsson 1981, Newbury & McCullough 1984, Rørslett 1989, Alasaarela *et al.* 1989, Wilcox & Meeker 1991). A lowered water level during winter generally causes an extension of the ice cover on the bottom, which brings about a negative effect on aquatic macrophytes. This applies in particular to a drastic decline of isoetids, which are particularly sensitive to these interventions, as was reported for various regulated lakes in Norway (e.g. Rørslett 1984), Sweden (e.g. Quennerstedt 1958) and Finland (Hellsten *et al.* 1996). Water level rise during summer also inflicts heavy erosion, which in turn especially affects helophytes such as common reed (*Phragmites australis*) and horsetail (*Equisetum fluviatile*). Decreased water level fluctuation and especially a diminished spring flood affects the vertical distribution of flood tolerant *Carex*-vegetation, which plays a key role in northern ecosystems. Changes caused by the water level regulation of Lake Kemijärvi in aquatic macrophytes, are exceptionally well documented (Malmström 1959, Hyvärinen 1964, Hellsten & Joronen 1985, Hellsten *et al.* 1999, Hellsten 2002).

The **species composition of macrophytes** showed only a slight change compared to the situation before main interference (Table 7). Malmström (1959) and Hyvärinen (1964) found altogether 46 species also including helophytes. Later studies of Hellsten & Joronen (1986) showed that there were only 37 species left in 1982-83. Last observations from summer 1998 indicated that there were only 29 species, but the research area was much more limited (Hellsten *et al.* 1999). The comparison of the frequencies of some macrophyte species before and after water level regulation is shown in Fig. 6. Several common species have completely disappeared after regulation. The very common elodeids *Myriophyllum alterniflorum* and *Ranunculus peltatus* were not found anymore. The previously frequent nymphaeids *Nuphar lutea* and *Nymphaea candida* grew only in one place, whereas *Nuphar pumila* and *Polygonum amphibium* had disappeared. Representatives of the large isoetids showed the following trend: *Isoetes lacustris* disappeared, whereas the frequency of *Isoetes echinospora* remained more or less the same. There was also a complete disappearance of some rare elodeids such as *Potamogeton lucens*, *P. compressus*, *P. alpinus* and *Ranunculus confervoides*, but *Potamogeton perfoliatus* and *P. gramineus* were still very common. Some nymphaeids with a flexible survival strategy (*Sparganium* sp. and *Sagittaria natans*), maintained themselves in their growth areas. Helophytes have not been common in Lake Kemijärvi in its natural state and the very sparse stands of *Schoenoplectus lacustris* and *Phragmites australis* disappeared after regulation. On the other hand, *Equisetum fluviatile* was still quite common, despite its limited resistance against erosion. Species composition shows **good or high ecological status**.

“Increasing species” consisted of the small sized isoetids, such as *Ranunculus reptans*, *Subularia aquatica*, *Eleocharis acicularis* and *Elatine hydropiper* (Fig. 6). Due to the submerged peaty soils of Lake Kemijärvi some typical species of reservoirs were found (*Callitriche palustris*, *Alisma plantago-aquatica*, *Warnstorfia* spp., *Alopecurus aequalis*). Despite of the changes in water level, *Carex aquatilis* was increasing and *C. rostrata* became more common.

A number of “decreasing species” consisted of species sensitive to increased effects of ice and erosion (Fig. 6). Large sized isoetids, such as *Lobelia dortmanna* and *Isoetes echinospora*, cannot tolerate freezing of the bottom sediment, whereas *Isoetes lacustris* is also avoiding the zone where ice only touches the bottom. Therefore these species are good indicators of water level regulation. On the other hand, these species are an essential part of a littoral ecosystem and the type-specific communities also providing high amounts of benthic invertebrates. *Isoetes lacustris* is the best indicator of water level regulation with its growth area between the ice-pressure zone and the zone where light becomes a limiting factor (Rørslett 1984, Rørslett & Brettum 1989, Hellsten 2001). *Lobelia dortmanna* is also another one, but due to its southern oriented distribution it has been never found in Lake Kemijärvi. *Isoetes echinospora* does not tolerate freezing, but with its flexible habitus with bendable leaves it is able to survive in regulated lakes (cf. Rørslett & Brettum 1989). Only one of the large-sized isoetids is present and **ecological status is obviously moderate** (Table 6).

Another key-area of northern ecosystems is **flooded shore meadows** consisting largely of *Carex*-species. Areal changes of these systems were analysed by using aerial photos taken before regulation in 1957-59 and in 1997-2000 (see method Partanen & Hellsten 2002). According to the interpretation of aerial photos the area of littoral vegetation has decreased dramatically (Fig. 7). In the upper part only 3.4 % and in the lower part 15.5 % of vegetation cover is left. It can be clearly claimed that the change has been significant and **ecological status is moderate or less than moderate** (Table 7).

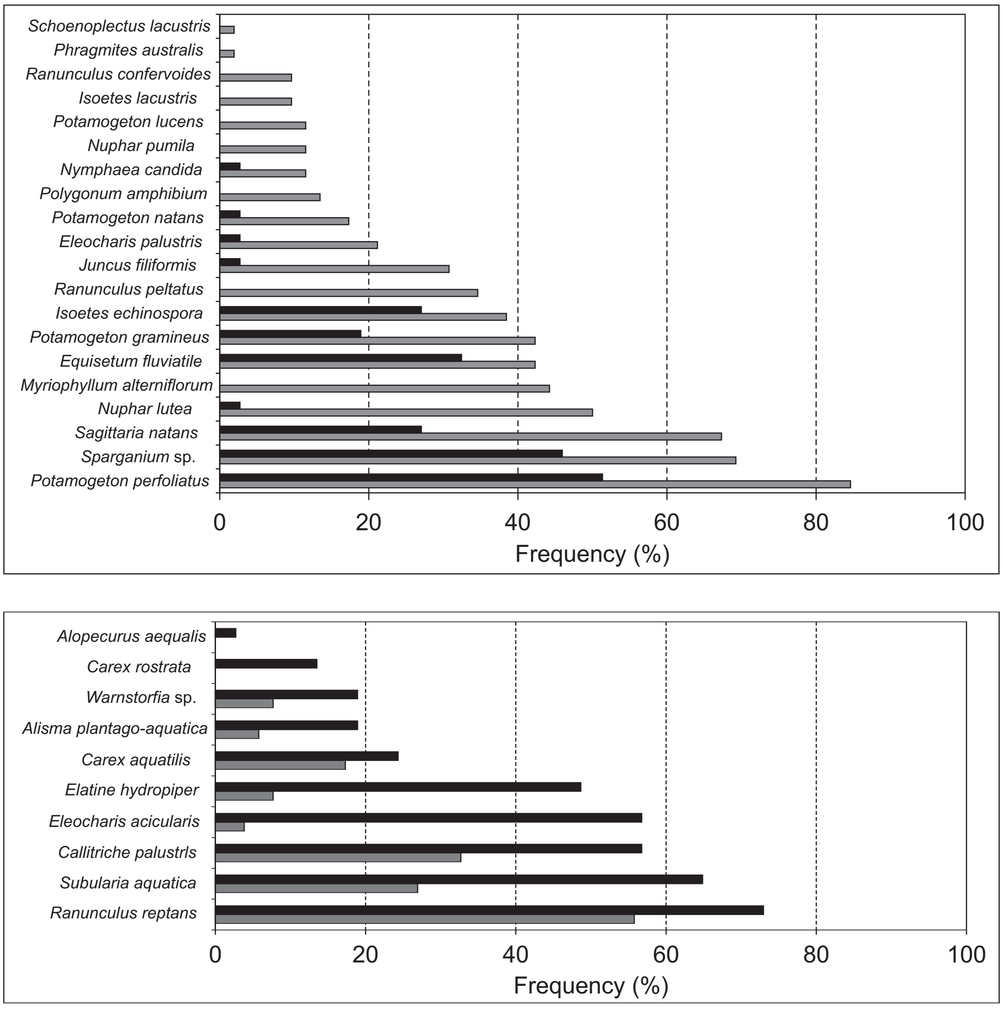


Fig. 6. Frequency (%) of some aquatic macrophytes in Lake Kemijärvi before (white columns) and after (black columns) water level regulation (Hellsten 2002). Species grouped according to response for regulation to decreasing (upper panel) and increasing (lower panel).

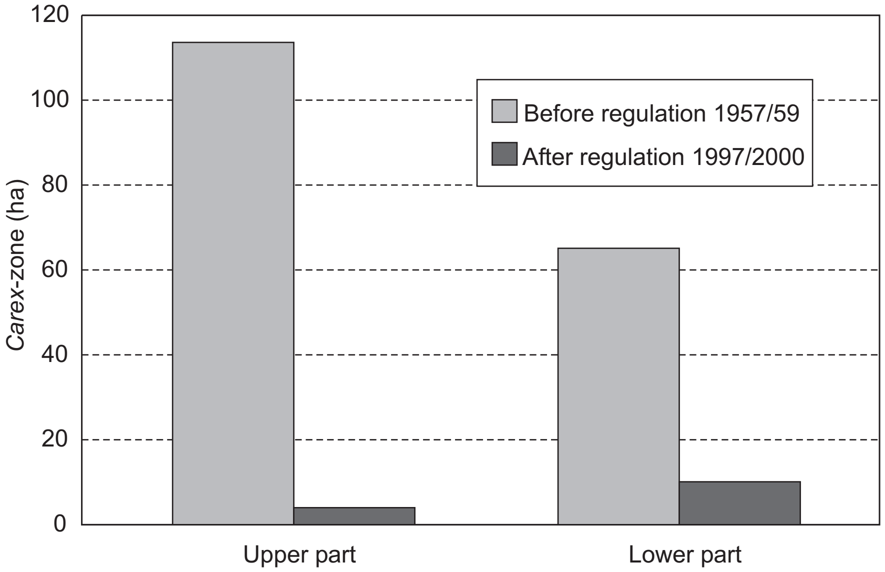


Fig. 7. Area of Carex-vegetation in the littoral zone before and after water level regulation. Estimation is based on analysis of 2.7 % of present shoreline.

Slightly smaller change was observed in the **vertical extension of *Carex*-vegetation**. Comparison of results of Hyvärinen (1964) and Hellsten *et al.* (1999) showed a clear difference (Fig. 8). Vertical extension has limited significantly as a result of the cut spring flood. Present values are only half of the values before water level regulation showing the changed status of littoral ecology, which reflects **moderate ecological status** (Table 7).

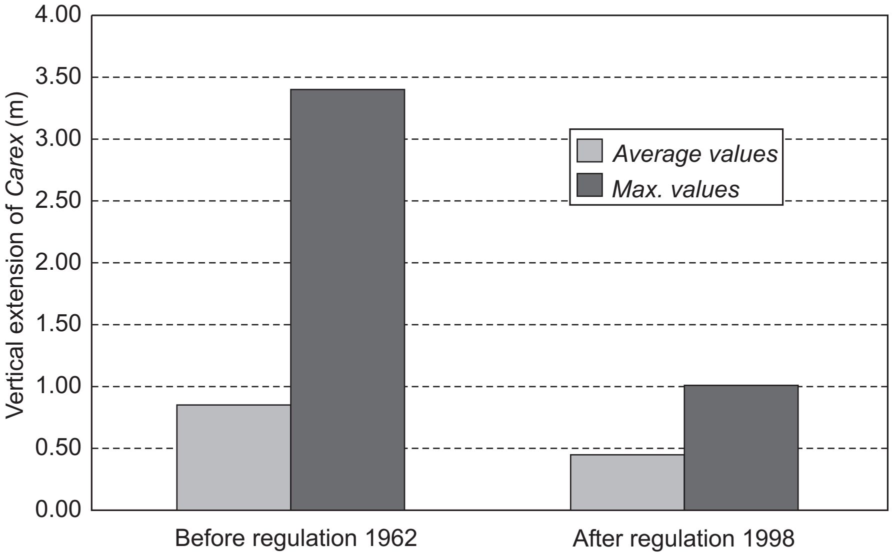


Fig. 8. Vertical extension of Carex-vegetation before and after water level regulation. Results are based on original drawings of Hyvärinen (1964) and Hellsten et al. (1999).

6.1.2 Macroinvertebrates

The WFD does not discriminate between littoral and profundal **benthic invertebrates**. In Finland, the data on profundal zoobenthos are more abundant and homogenous than those on littoral zoobenthos. However, in our case study we used the littoral zoobenthos because of their sensitivity to hydrological pressures. The assessment was based on the pre-regulation data, which was re-analysed by Tikkanen (1987). Hämäläinen & Luotonen (2001) compared the composition of taxa and taxa richness (as a measure of level of diversity) of Lake Kemijärvi zoobenthos to those in ten non- or slightly regulated reference lakes. The results were surprising; there were no significant differences in the number of typical taxa, typical taxonomic groups and taxa richness between Lake Kemijärvi and the reference lakes (Table 7). Lake Kemijärvi had 35 typical taxa compared to 36 in the reference lakes. The number of typical taxonomic groups was 19 and 21, whereas the total number of taxa were 42 and 47, respectively. Because the data from various lakes was relatively heterogeneous, sampling times, habitats and methods varying a lot, the results of the statistical analysis should be considered critically. Nevertheless, judging by the existing information on the number of taxons, the **ecological status of the lake is high.**

In the upper littoral, some important sensitive species have disappeared or become rare due to the impacts of ice and freezing of the sediment (Tikkanen 1987). Before water level regulation, the large-sized sensitive species *Ephemera vulgata*, *Pontoporeia affinis* and *Pallasea quadrispinosa* were quite common (Sormunen 1964). Due to differences in methods, the number of individuals per research area are compared (Fig. 9). The frequency of *Ephemera* was low and *Pontoporeia* (*affinis*) had completely disappeared. Only a few individuals of *Pallasea quadrispinosa* were observed during late summer samples from the Hietaselkä area, which is behind the natural threshold with a 4.5 metre regulation range. The distribution and abundance of large-sized macroinvertebrates in the natural and regulated lake was clearly different. Bearing in mind the low number of observations, the presence of sensitive species can be considered to indicate **moderate ecological status** (Table 7).

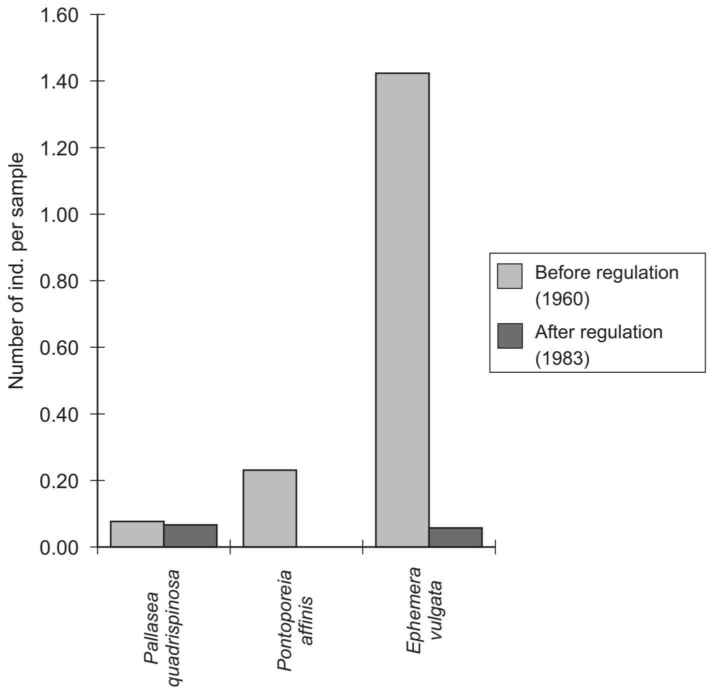


Fig. 9. Number of frost-sensitive macroinvertebrates per research site before and after water level regulation. Results are based on original samples of Sormunen (1964) worked out by Tikkanen (1987). Data consists of 26 samples before and 105 samples after regulation.

6.1.3 Fishes

The **fish fauna** of Lake Kemijärvi is comprised of 18 fish species (Kerätär *et al.* 2001). The number is the same as the average number of fish species in large Finnish lakes (> 100 km^2). The number of species before water level regulation is not well known, but Sormunen (1964) estimated that it was between 15 and 22 (Table 7). However, because of anthropogenic pressures salmon (*Salmo salar*), sea trout (*Salmo trutta*) and anadromous whitefish have disappeared from the fish fauna. Lake trout and whitefish stocks are maintained by intensive stocking. In addition, about 50 % of adult burbots (*Lota lota*) have become sterile (Korhonen 2000). The changes in anadromous fish fauna are due to the construction of power plants. There are 8 power plants between Lake Kemijärvi and the Gulf of Bothnia and only the lowest one is equipped with a fish ladder.

The most harmful impacts of regulation of Lake Kemijärvi are the increased mortality of whitefish eggs and decrease in food resources because of the changes in composition and abundance of zoobenthos (Huusko 1987, Heikinheimo-Schmidt & Huusko 1987, Tikkanen & Hellsten 1987). The main reason for the reproduction problems of burbot is not well known, but it can be related to the toxic compound in wastewater of the Kemijärvi pulp mill (Korhonen 2000).

Despite the significant changes of ecological environment, the changes in fish catches are quite small ranging from a pre-regulation average value of 5.3 kg/ha to a value of 4.9 kg/ha in recent decades. Kerätär *et al.* (2001) noted that the value depends on the lake area and is heavily affected by changes in fishing pressure, methods and especially fish stocking. Therefore the value doesn't directly indicate total fish biomass in Lake Kemijärvi.

As a conclusion the number of species indicates **high ecological status**, but the limitations in river continuum drops the ranking from high to **good ecological status** (Table 7). Good ecological status is based on the relatively large tributary area available for migrating species such as whitefish.

6.2 Physico-Chemical Elements

The changes in physico-chemical elements resulting from regulation are relatively small compared to biological elements (see chapter 5.1). The water level regulation and combined high discharge from reservoirs Lokka and Porttipahta have broken the winter stratification (Virtanen *et al.* 1993, Meriläinen *et al.* 1994). As a result of the temperature decrease the oxygen concentrations are higher near the bottom. The regulation has also had negative impacts on oxygen conditions. During the winter draw-down there is a deficit of oxygen in some isolated bays and in small and isolated deep water areas. Because of the short retention time and high discharges of water, Lake Kemijärvi is quite resistant against nutrient loading. Therefore, impacts of diffuse and point-source loading (paper mill, municipalities, fish farming) have had a relatively small and local impact on the nutrient status of the lake. The impacts of regulation on nutrient status are of minor importance.

6.3 Definition of Current Ecological Status

Due to the lack of a national ecological classification system for Finnish lakes, the definition of ecological status is based on our own expert judgement. It should be noted, that national work with the ecological classification procedure has already started and their results can significantly change our interpretation in the future.

Our focus was in the definition of moderate status because the border between good and moderate status is critical for the purpose of designation. Only water bodies with an ecological status lower than good can be designated as heavily modified.

Macrophytes: WFD determines moderate ecological status that *"the composition of macrophytic and phytobenthic taxa differ moderately from the type-specific communities and are significantly more distorted than those observed at good quality. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident."* A high decrease in vegetation cover shows definitely moderate changes in average macrophytic abundance (Table 7). On the other hand species composition has also changed clearly and the whole zonation pattern has changed significantly. Based on macrophyte data the ecological status can be seen as worse than good ecological status (Table 8).

The essential question is; do the discrimination of lakes and definition of type specific reference conditions affect the assessment of status? Lake Kemijärvi is quite an exceptional Finnish lake with a large low-lake-percentage drainage area. Consequently the spring flood before regulation was high and promoted wide vegetation zones with rich macrophyte flora.

Benthic invertebrate: The WFD defines moderate status as follows: *The composition and abundance of invertebrate taxa differ moderately from the type specific conditions. Major taxonomic groups of the type-specific community are absent*. The status of benthic invertebrates of Lake Kemijärvi is probably moderate (good) (Tables 7-8).

Fish fauna: The directive defines moderate status as follows: *The composition and abundance of fish species differ moderately from the type-specific communities. The age structure of the fish communities shows major signs of disturbance… to the extent that a moderate proportion of the type specific species are absent or of very low abundance*. As a consequence of changes in ecological environment (Table 7) and interpretation of the definitions for good and moderate status in the WFD, we assume that the status of fish fauna is good or moderate (Table 8). The key problem in the assessment was the vagueness of definitions of good ("slight changes") and moderate status ("differ moderately"). For instance, how many fish species can disappear until the status changes from good to moderate? The assessment was also hampered by the massive fish stockings.

6.4 Discussion and Conclusions

The ecological status of Lake Kemijärvi is good or moderate. Several decisions are needed in establishing the discrimination and classification systems, for instance

- Should we take into account the differences in (natural) water level fluctuation in the discrimination procedure? In Finnish lakes and rivers the timing and magnitude of spring flood affects, e.g., the width and zonation of littoral vegetation. If the natural water level fluctuation is neglected, it is difficult to identify the changes caused by regulation on littoral vegetation due to large variation of the type specific conditions.
- What are the biological quality factors? If the factors sensitive for water level regulation (e.g. littoral zoobenthos, extension of *Carex*-zone) are chosen, the impacts of regulation are going to have a more significant impact on the ecological status.
- What is the correct interpretation for terms in Annex V e.g. "differ moderately from type-specific conditions"?
- How is the biological status assessed from the status of macrophytes, macroinvertebrates and fish fauna? Is it minimum or average of those factors?

Table 8. Summary of the ecological status of Lake Kemijärvi.

Ecologial quality elements	Current status	Explanations
Biological quality elements		
Macrophytes	Moderate	Several species disappeared Abundance of littoral vegetation decreased (4-15 % left)
Macroinvertebrates	Moderate/good	Sensitive species almost totally disappeared
Fish fauna	Moderate/good	Anadromous fish species disappeared Problems in the reproduction of whitefish and burbot
Hydromorphological quality elements		
Hydrology	Significant changes	Regulation amplitude 7 m 2.2 m increase in water levels (open water period) Retention time in winter has shortened
Morphology	Moderate changes	41 km of shorelines have been protected by stones, 7 km channel in lake
Physico-chemical quality elements		
General conditions	Good/high	Impacts of diffuse and point source loading minor and local. Regulation has changed temperature and oxygen conditions in winter
Ecological status	Moderate	

Identification and Designation of Water Bodies as Heavily Modified

7

7.1 Provisional identification

7.1.1 A method for provisional identification of regulated lakes

The designation of heavily modified water bodies will be carried out in two phases. The provisional identification, which has to be undertaken by 2004 and the designation phase by 2009. In the provisional identification phase the aim is 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 possibilities to achieve it 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. Therefore, a method that is based on the use of indirect criteria would support the identification of heavily modified regulated lakes.

In most of the Finnish regulated lakes the alteration of water level fluctuation is the most important physical pressure. The morphological changes are of minor importance or they are primarily due to hydrological changes. The ecological impacts of water level fluctuation have been the target of intensive research since the 1980's and various methods have been developed to estimate the ecological impacts of lake regulation. A water level analysis tool has been developed to calculate the values for 50 different water level based indicators characterizing the impacts on e.g. aquatic macrophytes, littoral zoobenthos and fish reproduction (Hellsten *et al.* 2002). However, expert judgement is needed to interpret the results and to assess e.g. the ecological significance of water level fluctuation.

In order to identify the probably heavily modified regulated lakes we have developed a three-phased approach (Fig. 10). In the first phase the water levels of regulated lakes are compared to water levels of the same type of non-regulated lakes. Based on the results of this phase the lakes are divided into natural and modified lakes. In the second phase the changes of water levels caused by regulation are analyzed. After this phase the lakes are divided into slightly or moderately modified and probably heavily modified.

One of the basic ideas of the WFD classification system is to define reference conditions for each lake type and to assess the ecological status by comparing the current status to the reference status. The provisional typology of Finnish lakes suggests that the water level fluctuation can be taken into account if necessary. As a result we have divided lakes into three groups: lakes with watershed lake-percentage less than 7 %, 7-15 % or more than 15 %. The division is based on the statistical analysis of the water level fluctuation and characteristics of the drainage basin of 105 non-regulated lakes. The results showed that the most important factor affecting water level fluctuation was the lake percentage of the watershed. It explained nearly 70 % of the variation (Figure 10).

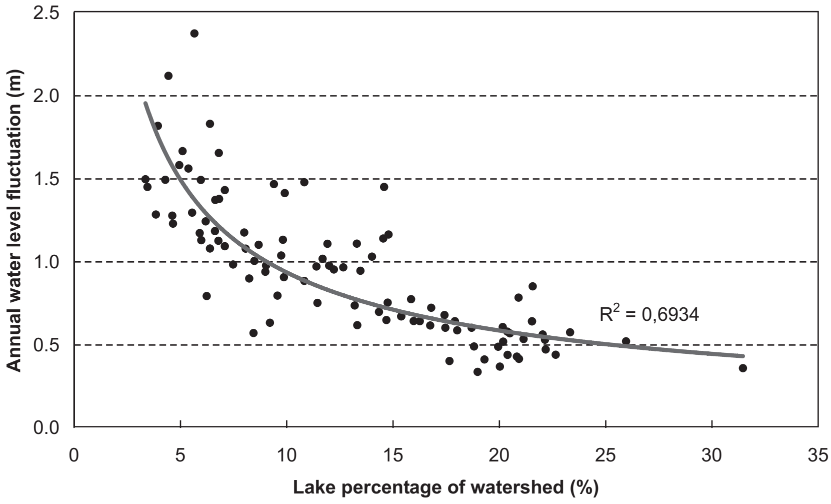


Fig. 10. The relationship between lake percentage of watershed and annual water level fluctuation.

The method is comprised of three main phases (Fig. 11).

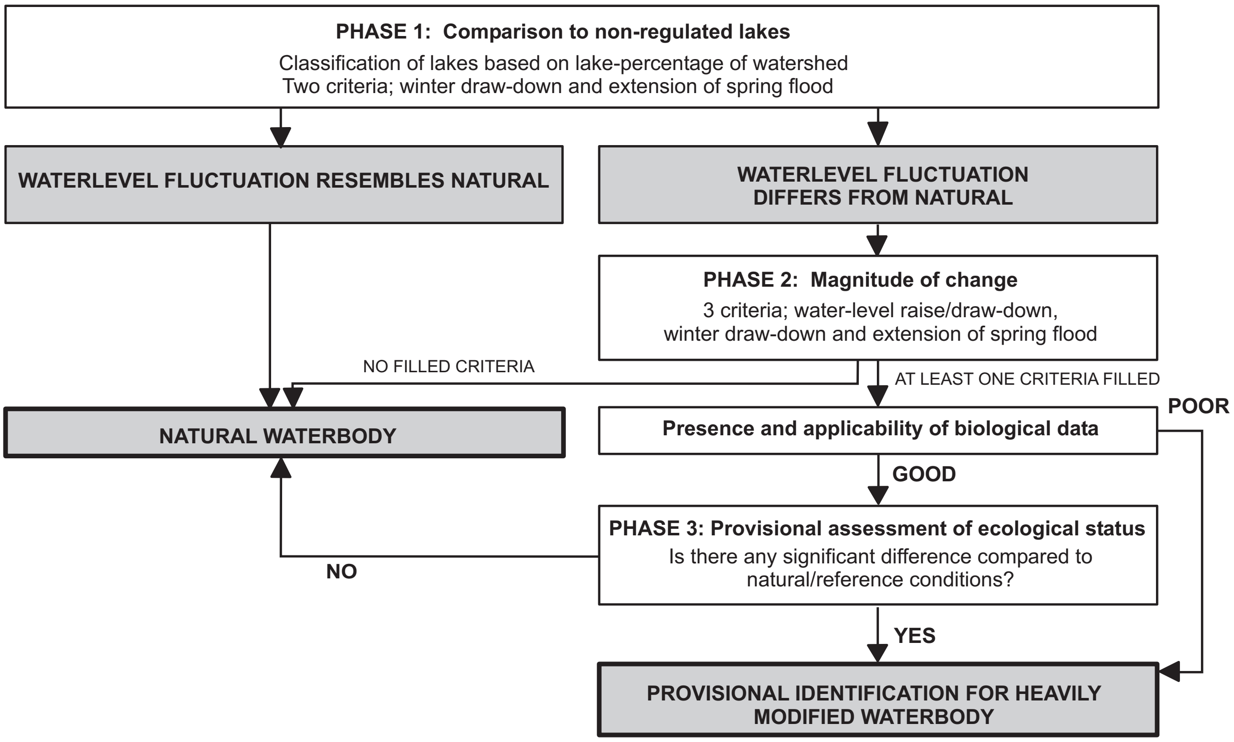


Fig. 11. Phases of the provisional identification of regulated lakes

PHASE 1: The first phase was to identify those lakes that belong to the same lake type and which deviate from lakes with natural water level fluctuation. Both in the first and second phase the same two criteria have been applied, the magnitude of winter draw-down and extension of spring flood. The choice of the criteria were based on biological data from more than 20 regulated lakes and statistical analysis. Aquatic macrophyte and littoral zoobenthos data analyses suggest that in Finland where the ice cover period normally lasts from December to May the winter draw-down has significant adverse impacts by freezing sensitive species. The magnitude of the spring flood affects vegetation zonation, e.g. in lakes with a small spring flood the sedge (*Carex*) zone has been observed to be very narrow. The threshold values for criteria were based on the data from 105 non-regulated lakes (Table 9).

Table 9. The values of criteria to identify those regulated lakes where water level fluctuation differs from natural.

	Lake percentage of watershed		
	<7%	7-15 %	>15 %
Winter draw-down	> 0.6 m	> 0.6 m	> 0.3 m
Magnitude of spring flood	< 0.6 m	< 0.25 m	< 0.15 m

PHASE 2: In the second phase the changes in mean water level are considered as well as the criteria of phase 1. For each group various threshold values for criteria were applied (Table 10). However, the uplift or lowering of the mean water level might have dramatic impacts on the water ecosystem. Impacts depend on many lake specific factors (e.g. mean depth, area, time after action). Additionally, there are many open questions related to implementation of the WFD. These factors cause uncertainty, which hampers the identification of heavily modified water bodies. Therefore, two different sets of threshold values have been applied for designation criteria (see Table 10). In order to be identified as heavily modified at least one criterion has to be fulfilled.

The raising or lowering of the average water level in the beginning of regulation have not yet been included in the analyses. The investigated lakes have been relatively large varying from 2 km^2 to 1 100 km^2 with the mean size of 300 km^2. In large lakes the changes caused by the lowering of the mean water level are not as significant as in small lakes where it can lead e.g. to a substantial increase of aquatic macrophytes. Whereas, a rise of the mean water level can increase erosion and cause landslides.

Table 10. Threshold values for the criteria applied in phase 2.

	"Broad criteria"	"Strict criteria"
Increase in the winter draw-down	1.5 m	3 m
Decrease in the spring flood	0.7 m	1.2 m
Change in mean water level during the open water period	Expert judgement	

PHASE 3: The third phase is optional. In this phase a trend-setting assessment of biological status will be carried out only in those lakes where good biological data is available. The results of the biological analysis can confirm or reject the result of the second phase.

7.1.2 The results of the provisional identification method

PHASE 1: The magnitude of winter draw-down of Lake Kemijärvi has been in the current regulation 6.75 m. The threshold value for lakes which lake percent of water shed less than 7 % was defined to be 0.6 m. Consequently, the draw-down of Lake Kemijärvi is over ten times higher than the threshold value. The threshold value for spring flood is 0.6 m and the magnitude of spring flood in current regulation have been 0.32 m. To sum up both criteria differ from non-regulated lakes of the same type.

PHASE 2: The comparison to natural water levels reveals that the change in water levels has been dramatic. The winter draw-down has increased from 0.55 m to 6.75 m and the spring flood has decreased from 2.5 m to 0.3 m. Additionally, the mean water level during open water period have increased nearly by 2 m. Based on these three criteria it is fully evident that Lake Kemijärvi belongs to the group provisionally heavily modified lakes.

7.2 Necessary Hydromorphological Changes to Achieve Good Ecological Status

As described earlier in chapter 5.3 the regulation of Lake Kemijärvi has had significant impacts on the littoral ecosystem and fish stocks and substantial improvements are probably needed before a good ecological status can be achieved. Good ecological status for Lake Kemijärvi was defined as follows:

- Erosion of shoreline, especially from sandy shores would decrease.
- Frost sensitive species should exist both among the aquatic macrophytes and littoral macroinvertebrates. 20-30 % of productive littoral zone should remain non-frozen.
- Zonation and width of littoral vegetation would become more natural. Width of *Carex* zone is more than 60 % of natural state (or reference conditions).
- Reproduction of brown trout and migrating whitefish would improve in the tributaries of Lake Kemijärvi.
- Survival percentage of eggs of autumn-spawning fish (whitefish) and their food resources (littoral macroinvertabrates) would increase.
- The current water quality is propably good enough to fulfil the criteria of good physico-chemical status.

To achieve these goals crucial modifications to current regulation practice have to be carried out.

- Minimum water level at the beginning of February (date which determines the depth of the frozen zone in Northern Finland) should be above N_{43}+147.40 m (currently N_{43}+146.90 m)
- Winter draw-down should be only 2-3 m at its maximum (currently 7 m)
- Water level during open water period should not exceed N_{43}+148.75 m (currently HW is N_{43}+ 149.00 m)
- Water level fluctuation during summer time should be increased by 0.7 m or current fluctuation is adequate depending on the reference (see Fig. 12)
- Reproduction areas of brown trout and migratory whitefish should be restored in the tributaries of Lake Kemijärvi.

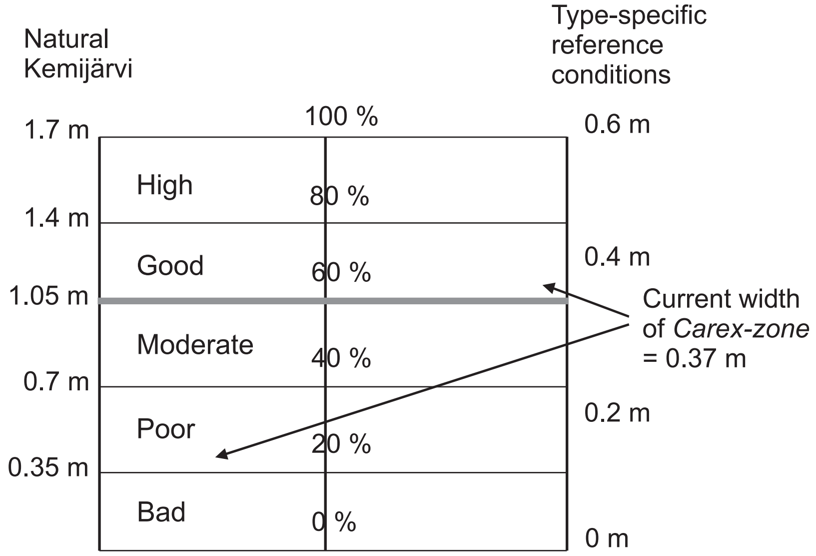


Fig. 12. The relationship between biological status of macrophytes (indicator: vertical extension of Carex-zone) and reference conditions in Lake Kemijärvi. Natural Kemijärvi represents the situation before regulation and type-specific reference conditions represent the width of the Carex-zone (calculated by REGCEL-model) in lakes with similar lake percentage of the drainage basin as in Lake Kemijärvi.

In Finland many research projects concerning the impacts of lake regulation have been carried out since the 1980's. As a result, current knowledge of the relationship between water level fluctuation and littoral flora and fauna is relatively good. In addition, there are several well-developed methods for ecological impact assessment. Especially the impacts of freezing of sediment and the changes in spring flood on littoral vegetation have been well documented (Hellsten 1997, 2001). However, there is still a great need for further studies where the biological responses of various regulation practises in different types of lakes are compared. The setting of ecological target water levels was partly based on these studies and partly on expert judgement.

In 1999 a large lake regulation development project was started in Lake Kemijärvi. One of the main goals is to assess the needs and possibilities to alleviate the adverse impacts of current regulation. The project comprises several subprojects where the ecological, social and economic impacts of regulation are assessed and various regulation alternatives are compared. The impacts of the good ecological status regulation (GES-regulation) on recreational use, flood protection and hydropower were roughly estimated by utilising the preliminary results of this regulation development project (Table 11). The impacts on recreational use are based on the results of field surveys, a mathematical model and the results of a questionnaire directed to the users of Lake Kemijärvi. The impacts on floods and energy production were assessed by applying heuristic estimations and simple calculations. The assessment comprised both Lake Kemijärvi and River Kemijoki. The impacts on the flows of the River Kemijoki were analysed by the Scottish DHRAM –model (Black *et al.* 2001, Hellsten *et al.* 2002).

Table 11. The impacts of GES-regulation of Lake Kemijärvi.

Variable	Impact
Erosion of shorelines	Moderate decrease in erosion of sandy shorelines.
Littoral ecosystem	Frost sensitive species of aquatic macrophytes and zoobenthos will recover.
Fish stocks	Reproduction and food resources of whitefish will improve.
Recreational use and fishing	Benefits 0.1-0.5 million Euros/year. Positive impacts during winter and spring. Negative impacts especially in wet conditions due to too high water levels and flows. If water level fluctuation in summer is increased then negative impacts and contradictions with recreational users will occur.
Flood damages	Flood risk in Lake Kemijärvi and River Kemijoki will significantly increase. Damages for buildings and infrastructure.
Hydropower production	Losses 3 million Euros/year (30 % of the total benefits of Lake Kemijärvi regulation)

7.3 Assessment of Other Environmental Options

The WFD states that member states may designate water bodies as heavily modified "if beneficial objectives served by the modified characteristics of the water body cannot, for the reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means, which are a significantly better option".

The objectives of Lake Kemijärvi regulation, namely hydropower production and flood protection, have been met very well. The annual benefit for hydropower production is about 10 million Euros and there have been no floods in Lake Kemijärvi after regulation. However, there are still some flood-prone areas in the city of Rovaniemi about 100 km downwards from Lake Kemijärvi. The water level of Lake Kemijärvi is lowered by seven metres during the ice-cover period in order to increase the storage capacity for spring flood. The cessation of regulation would cause significant flood damages in Lake Kemijärvi and the River Kemijoki. In the following chapters we discuss the possibilities to achieve the benefits of current regulation by other means.

There are, at least in theory, several alternative ways to decrease flood damages in Kemijoki watercourse.

- Increasing storage capacity in upper river basin by constructing new reservoirs. The construction of new reservoirs is definitely not a better environmental option than the current regulation of Lake Kemijärvi. In addition, the construction of new reservoirs would cause strong conflicts between different stakeholders. The previous plan to build the Vuotos reservoir at the mouth of the River Ylä-Kemijoki near Lake Kemijärvi was recently cancelled in Finnish High Court.
- Changes in regulation practices in upstream Lokka and Porttipahta reservoirs would have only minor impact on floods of Lake Kemijärvi and the River Kemijoki.
- Storing the floodwaters occasionally in the wetlands and forests would be an expensive and inefficient way to affect the floods, e.g., in the Rovaniemi area. There would also be many technical difficulties in this option.
- Blocking the ditches of the peatlands and forests would probably cut the flood peak. However, it would have negative impacts on the drainage status of forests and is therefore not a possible option on a large scale.
- If the risk of floods is more seriously taken into account in land use planning, it can decrease possible flood damages in the future. However, it does not decrease damages for current infrastructure and buildings.

- Dams and embankments can be applied in the most sensitive areas, but it is disproportionately costly to protect summer cottages which locate in flood prone areas, e.g. along the shores of Lake Kemijärvi.

In Finland over 15 % of electricity is produced by hydropower plants. Hydropower also plays a crucial role in balancing the energy production and fluctuation of energy consumption. In addition, it increases reliability to electricity networks. The role of the Kemijoki watercourse in Finnish energy production is significant; it comprises one third of Finnish short-term regulation capacity. If the hydropower production is decreased, then new capacity is needed. Nuclear power and wind power cannot replace hydropower due to their poor suitability for short-term regulation. As a matter of fact, an increase in wind power will increase the need of adjustment capacity! Gas turbine plants could replace hydropower. However, their efficiency is lower, atmospheric emissions are higher and the production costs of electricity are higher compared to existing hydropower plants.

7.4 Designation of Heavily Modified Water Bodies

We carried out the designation of heavily modified water bodies by using the procedure presented in the flow chart in Fig. 13. The procedure included several questions explained in detail in the following chapters.

QUESTION 1: Is good ecological status achieved in 2015?

The answer is probably **NO**, because the ecological status of Lake Kemijärvi will probably be moderate in 2015. The regulation has started 36 years ago and significant differences in water level regulation practice or in hydrological years are not expected. It can be easily concluded that there will be no special trend in the biological quality elements caused by water level fluctuation. It is obvious that the pollution load from paper mill and municipalities will still decrease in the near future. Major changes in land use are very unlikely.

However, there are still many open questions in the implementation of WFD and thus the result of the classification is quite uncertain. As the general status of large Finnish lakes is good, impacts that are considered significant in Finland may be non-significant at the European level. In the WFD context this can mean at the European level that the criteria for good ecological status can be lower than they would be if they will be set nationally by Finnish experts and politicians. However, the ecological quality scale will be intercalibrated between Finland, Sweden and Norway, which have quite similar views of water status.

QUESTION 2: Are physical changes a major reason for not achieving good status?

The most harmful impacts on the aquatic ecosystem are caused by hydrological alterations. Although the morphological alterations are on the Finnish scale exceptionally extensive, their impacts on the ecological status of the Lake Kemijärvi are not as significant as the impacts of water level regulation. The impacts of other anthropogenic pressures are of minor importance. Consequently, the answer for question two is **YES**.

QUESTION 3: Can good ecological status be achieved without causing significant adverse effect on use?

The results of impact assessment suggest that the answer is **NO**. On one hand, the GES-regulation would have significant adverse impacts on hydropower production and flood protection and on the other hand it would have positive impacts on the water ecosystem and fishing. The impacts on recreational use would be both positive and negative. However, it is quite obvious that in this case the negative impacts of GES-regulation would be more significant than its positive impacts.

QUESTION 4: Are there alternatives, which serve the same beneficial objectives as the regulation and which are feasible in terms of technical, economic and environmental aspects?

The most harmful impacts on nature are caused by winter draw down which serves the objectives of hydropower production and flood protection. The alternative means to reduce flood damages are inefficient and more expensive than the current regulation of Lake Kemijärvi. Furthermore, there is no single source of electricity that could replace hydropower with an environmentally better option and without disproportionate costs. Answer for this question is thus **NO** and as a result **Lake Kemijärvi can be designated as a heavily modified water body.**

We ended up with a conclusion where Lake Kemijärvi was considered as one water body from outlet up to Pelkosenniemi. It would also be possible to consider areas of milder regulation as separate water bodies. Because of the bottom-weir the lowest water level in the upper part of Lake Kemijärvi is 3.75 metres higher than in the lower part of the lake. In addition, there are four bays, which are isolated by bottom weirs. Although these areas covered more than 40 % of the total lake area, there are not so significant differences in the impacts of regulation in the upper part and lower part of the lake. Most critical issues such as erosion caused by increased summer water level and changes in spring flood are the same in all parts of lake. Also the share of non-frozen zone is more or less same, because the water level is decreasing similarly in the beginning of winter. Small lakes, which are permanently detached from Lake Kemijärvi by embankments, were identified as separate water bodies because their regulation practices and problems are different. The main problems in these lakes are related to poor water quality.

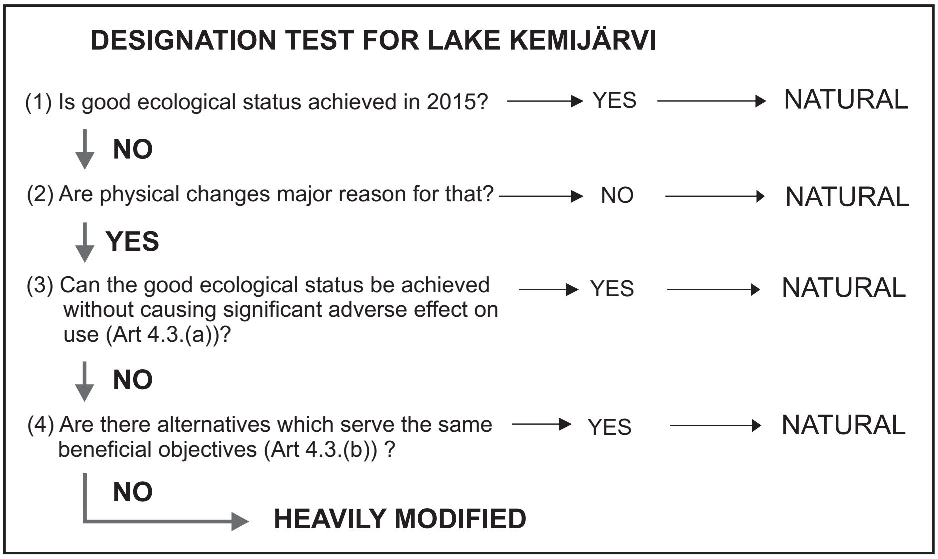


Fig. 13. The phases of the designation test.

7.5 Discussion and Conclusions

Our experience suggests that the designation process is quite laborious. In cases where the result of the designation process is evident, the process can even cause some frustration. However, the designation process of the Lake Kemijärvi case study was quite straightforward and generally there were no major problems to find answers for the designated questions presented in Fig. 13., although many important questions in typology and classification systems are still open.

Many research and development projects have been carried out in Finland during the last decades aiming to alleviate the harmful impacts of lake regulation. As a result, several methods to assess ecological, social and economic impacts of regulation have been developed (Marttunen *et al.* 2001). Although the approach in Finnish projects has deviated from the designation process in many respects, the methods and results are highly applicable also in the WFD context. In lakes it is possible to apply these results, e.g., to the designation test according to Article 4.3.b. In rivers the situation is not as good as in lakes. The current water level analysis tool (REGCEL) for regulated lakes will be further developed by testing the relationships between biological and hydrological parameters. A project to evaluate the applicability of the Scottish DHRAM-model to assess the impacts caused by river regulation has also been launched.

At the moment there are no general principles to assess the significance of impacts of regulation on water ecosystem in Finland. The assessment is carried out case by case and it is based on the changes in magnitude of water level fluctuation and in its temporal variation. In lakes the major criteria are water level decrease in wintertime and changes in spring flood. Water level decrease during the ice-covered period can have large impacts on littoral zone biota because some aquatic plants and macroinvertebrates cannot tolerate freezing. The sensitivity of the water body to water level fluctuation is usually considered, e.g., the slope of the littoral zone, quality of soil and water, when the significance of water level fluctuation is estimated.

Our experiences propose that in many cases there is no need for detailed studies in order to find an answer to question 4. For instance, there are no real alternatives for hydropower in Finland at the moment, and thus the answer for question 4 will be the same in all regulated lakes. This regards also flood protection, which is another common and important objective of lake regulation. In Finland one obstacle against flexible changes in water level regulation is current water legislation, which requires high compensations for land owners, extensive studies and public hearings to be carried out in all cases where the mean water level rise is more than 5 cm.

A directive for the promotion of electricity produced from renewable energy sources has been launched in 2001. The aims of that directive are partly opposite compared to WFD. How the objectives of these two directives will be reconciled in watercourses where the production of hydropower is an important use? In order to assess impacts on power production the price for electricity during different times of the year have to be defined. Our question is; what is the right price for electricity? In Finland the price of electricity is among the lowest ones in the European Union. As a result the impacts of the same modification in regulation practice can considerably deviate in terms of losses for hydropower production in different countries. Another important question is the right decision-making level. Should some of the decisions related to designation be made on a national level or are they all made at the regional level? For instance, if WFD changes regulation practices in many water bodies it can indirectly affect CO_2-emissions and thus be contradictory to the national need to reduce emissions. As a summary, we would like to highlight the importance of flexibility in the details of the designation process depending on the characteristics of the water body.

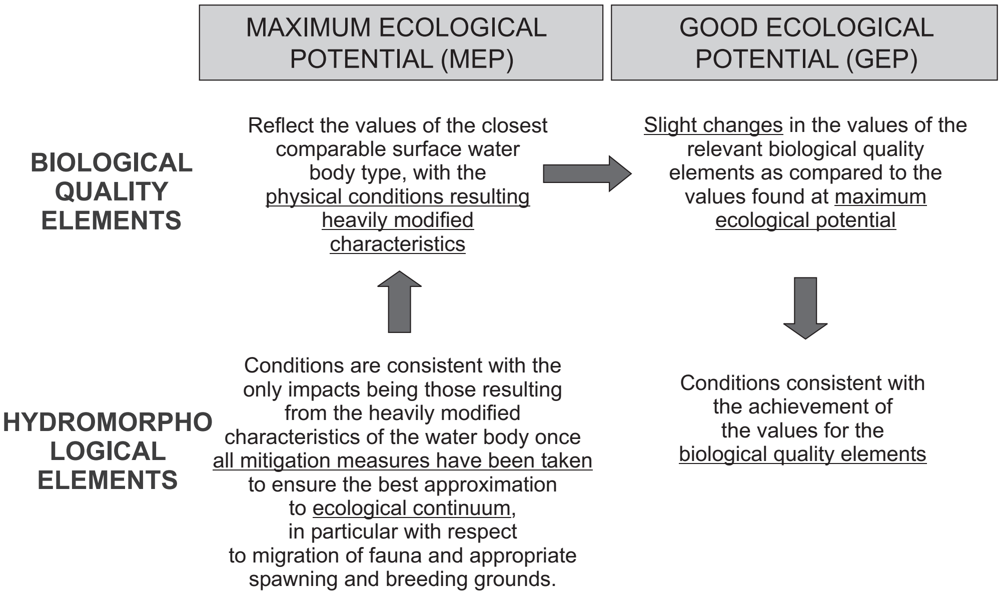
8

Definition of Maximum Ecological Potential

8.1 Determining Maximum Ecological

Lake Kemijärvi is designated as a heavily modified water body in our case study. The ecological target level for an HMWB is good ecological potential (GEP), whereas maximum ecological potential (MEP) defines reference conditions on which ecological assessment is based. According to WFD (Annex V 1.2.5) in maximum ecological potential (MEP) *"the values of the relevant biological quality elements reflect, as far as possible, those associated with the closest comparable surface water body type, given the physical conditions, which results from the heavily modified characteristics of the body"*. The hydromorphological elements at MEP *"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 approximate spawning and breeding grounds"*.

From our point of view there should be a link between hydro-morphological conditions and biological elements in MEP, because the possible improvements in hydro-morphological conditions may have positive impacts on, e.g., macrophytes, macroinvertebrates or fish fauna (Fig. 14). It is also difficult to determine MEP and GEP separately due to similar determination principles and only a slight difference in the status of biological quality elements. Therefore, in our approach both are considered together.



Reflect the values of the closest comparable surface water body type, with the physical conditions resulting heavily modified characteristics

Slight changes in the values of the relevant biological quality elements as compared to the values found at maximum ecological potential

Conditions are consistent with the only impacts being those resulting from the 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.

Conditions consistent with the achievement of the values for the biological quality elements

Fig. 14. Relationship between biological quality elements and hydro-morphological conditions in MEP and GEP.

In contrast with high and good ecological status in natural water bodies, MEP and GEP have to be defined case-by-case, taking into account the current use of water body and the possibilities to alleviate existing adverse ecological impacts. Consequently, there should be clear principles to determine, which methods should be included in the MEP or in the GEP. This especially regards the determination of the limit or "slight deviation" between MEP and GEP. To define MEP for Lake Kemijärvi we applied the procedure depicted in Figure 15. Instead of the closest comparable water body, the natural status of Lake Kemijärvi was used as a reference status due to relatively good biological data before major anthropogenic pressures and because there was no good reference lake available.

In order to illustrate the differences between MEP and GEP we introduced a schematic figure, where the limit between MEP and GEP is a simple function between ecological significance and effects on use and/or costs (Fig. 16). Methods used to reach GEP should have positive ecological impacts with low costs or only slight effects on use, whereas in the MEP higher costs and impacts are accepted. However, there can also be non-acceptable measures comprised of actions that are, e.g. expensive, inefficient or have significant adverse impacts on use. The ecological, social and economic impacts of various methods depend on many site-specific factors and therefore a mitigation method which is non-acceptable in one water body can be included into the GEP or into the MEP in another water body. As a result, the impacts of measures have to be assessed case by case.

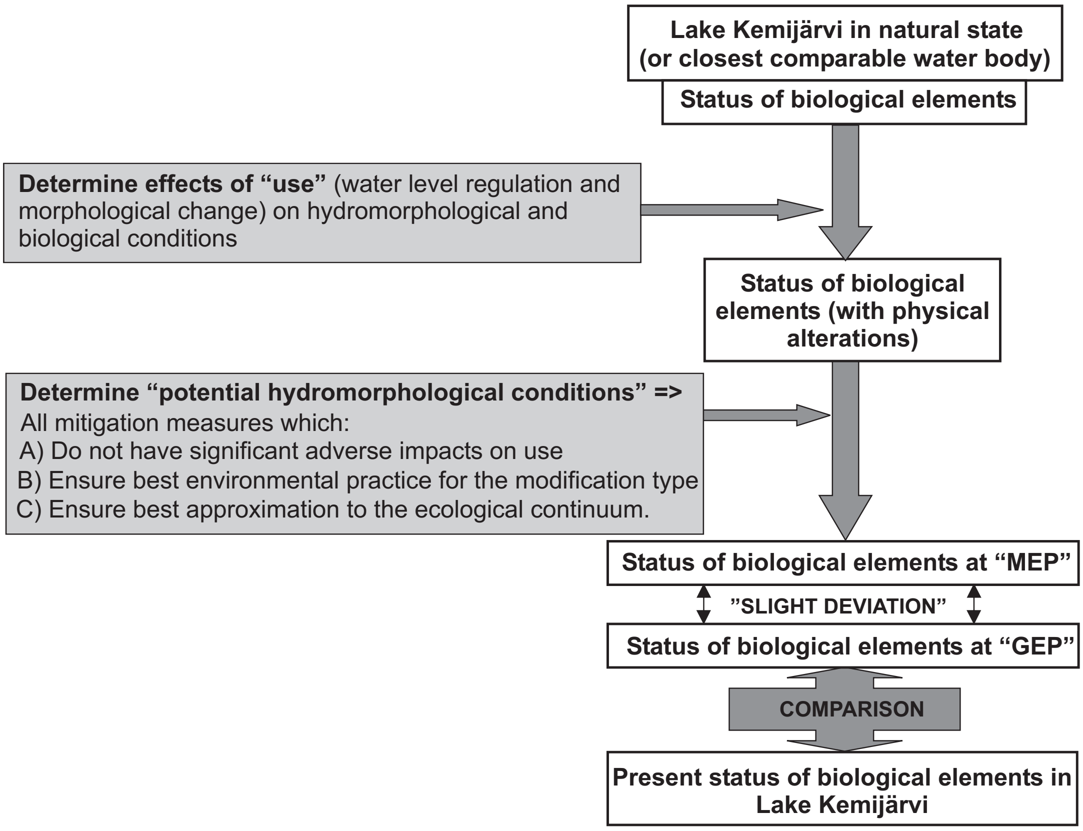


Fig. 15. General procedure to determine MEP and GEP for Lake Kemijärvi.

As the definitions of MEP and GEP are very vague, there are many open questions to be decided. In our case study one of the most essential question is whether "all mitigation measures" includes changes in regulation practice? Does the term "given the physical conditions" in Annex V really mean that mitigation measures considered in setting MEP must not impact the use, which has caused its designation as an HMWB. We suggest that there are at least three different options to consider changes needed to regulation practice in MEP.

- Option 1: No changes in regulation practice are required ("given the physical conditions").
- Option 2: Only such changes in regulation practice are allowed which have insignificant adverse impacts on uses (analogy to article 4(3)).
- Option 3: Only such changes in regulation practice are allowed which have greater benefits than losses and adverse impacts on uses are not significant.

Options 2 and 3 can, at least in theory, lead to the situation where the regulation practice is changed every sixth year by small steps, which can result in significant losses for the original use of a lake in the long run. However, in Lake Kemijärvi case study we followed the third option, which means that all effects were estimated carefully, mainly by expert judgement.

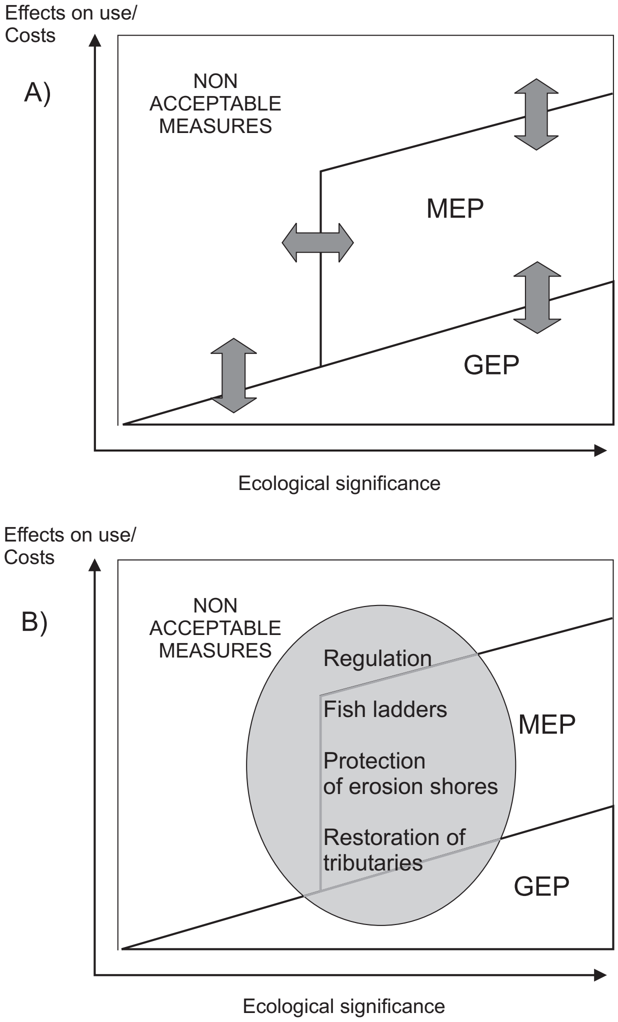


Fig. 16. A) Schematic view of the relationship between ecological significance and effects on use. Maximum ecological potential (MEP) and good ecological potential (GEP) are positioned as a function with these factors. See text for details of the term non-acceptable measures. B) Placement of some mitigation measures.

8.2 Measures for Achieving MEP

In this chapter we apply the two-phase procedure depicted in Fig. 15 to determine the measures included in the MEP in Lake Kemijärvi. First, we describe the effects of hydro-morphological changes on the chosen ecological quality elements of Lake Kemijärvi and then assess the impacts of various mitigation measures.

8.2.1 Effects of use on ecological status (phase 1)

Regulation is the most important anthropogenic pressure in Lake Kemijärvi (see Chapter 5). In order to get an overall picture of the impacts of hydrological changes on biological conditions, the REGCEL water level analysis tool was applied. The impacts of morphological alterations were assessed by expert judgement. The results presented in Table 12 suggest that the enhancement of ecological status of Lake Kemijärvi in terms of macrophytes or zoobenthos requires changes in current regulation practise. The impacts of other anthropogenic pressures are relatively insignificant. For instance, the impacts of morphological changes are of minor importance, although locally the adverse impacts can be significant. However, fish fauna of Lake Kemijärvi are mostly affected by morphological changes in the River Kemijoki downstream and intensive fish stocking (brown trout and whitefish). Due to the construction of power plants anadromous fish species have disappeared.

8.2.2 Assessment of the mitigation measures (phase 2)

There are various methods to improve the ecological status of Lake Kemijärvi. Among the most important ones are the alteration of water level fluctuation, habitat restorations both in Lake Kemijärvi and on tributaries, and the installation of fish ladders. The applicability of those methods in terms of ecological significance, costs and use in Lake Kemijärvi are presented in Fig. 16.

Ecological regulation practice (ERP)

In order to achieve good ecological status, major modifications to current regulation practice are needed as described in Chapter 7. Such changes would have significant adverse impacts on use and therefore they were not considered acceptable. However, this does not necessarily eliminate a need to revise the current regulation practice in MEP.

It was found that the impacts of regulation, both positive and negative, depend on the extent of change in regulation practice. Generally, minor changes in water level fluctuation result in minor impacts. However, certain changes in regulation practice can have significant negative impacts and only minor positive impacts on the ecological status of the lake. In order to find out the possibilities to improve the ecological status of the lake we defined an ecological regulation alternative and assessed its impacts (Table 13). The procedure of determining ecological regulation practice (ERP) has been applied in several Finnish regulated lakes during regulation development projects (Hellsten *et al.* 1996, Marttunen *et al.* 2001).

Table 12. The Impacts of pressures on biological quality elements in Lake Kemijärvi.

	Macrophytes	Zoobenthos	Fish fauna
Lake regulation	Significant negative impact	Significant negative impact	Moderate negative impact
Morphological alterations in Lake Kemijärvi	Only local negative impact	Only local negative impact	Minor negative impact
Construction of power plants downstream	No impact	No impact	Significant negative impact (anadromous fish species disappeared)
Construction of reservoirs and power plants upstream	No impact	No impact	Moderate negative impact (down-migration of whitefish)
Bottom weirs	Local positive impact	Local positive impact	Local positive impact
Deteriorated tributaries	No impact	No impact	Slight negative impact
Pollution loading	Minor and local negative impact	Moderate but local negative impact	Minor negative impact (reproduction of burbot)
Fish stocking	No impact	Slight impact	Moderate positive impact
Fishing	No impact	No impact	Moderate impact
CONCLUSIONS	The impacts on macrophytes are mainly due to the regulation	The impacts on zoobenthos are mainly due to the regulation	The impacts on fish fauna are mainly due to the alterations outside Lake Kemijärvi and fish stocking and fishing

One of the most harmful effects of water level regulation is increased winter water draw-down. As explained in earlier chapters the most critical water level for the littoral ecosystem is the middle winter water level in the beginning of February ($W_{FEBRUARY}$). The higher the water level, the smaller the area of frozen bottom zone. A rise in water level would increase the survival rate of some zoobenthos and macrophytes species. The significant positive impact on ecological status may occur only if part of the productive zone would remain non-frozen. Currently, the productive bottom zone is totally frozen every year. As a result a major increase in water levels (50 cm or more) would be needed in order to significantly improve the ecological status of the littoral ecosystem (Table 13). However, it would have considerable negative impacts on hydropower production.

The spring flood is an important part of northern lake ecosystems. A slight 0.5 metre increase of the water levels in May ($W_{DURING\ ICE-OFF}$) would have slight positive effects on e.g. zoobenthos (Table 13). It would also have a moderate positive impact on the ecological continuum by enabling spring spawning fishes, particularly northern pike, to reach their spawning grounds sooner than in the present situation. However, hydro power production as well as flood protection during wet springs would be harmed.

The increase of the lowest water levels in spring would have positive impacts on ecological status. In order to achieve significant improvements, however, there should be a rise of water level by more than 2 metres (Table 13). This would cause losses for hydro power production (approximately 0.5 million Euro/year) and increase flood risk especially during wet springs. Additionally, a slight positive impact on ecological continuum would follow from the rise in water level.

A lowering rhythm in water levels during summer is a key factor for littoral zonation in northern lakes. Wide macrophyte zones offer a great variety of different habitats for benthic fauna as well as young fishes. For instance, a 0.3 metre increase in summer water level fluctuation (W_{MAX} - W_{MIN}) would have a positive impact on macrophytes and also indirectly on zoobenthos and northern pike, as it enlarges pike's reproduction areas (Table 13). A lowered water level would also diminish erosion in the lake as well as the flood risk. However, a decrease in the lowest summer water levels could have at least moderate detrimental impacts on the recreational use of shorelines and some negative impact on hydropower production.

In many regulated lakes water levels are raised during autumn in order to increase regulation capacity for hydropower production. Generally, erosion is at its highest during autumn when the water level is usually high, heavy winds occur, and shoreline is partly without sheltering vegetation cover. Lowering of the highest water levels (W_{MAX}) in autumn by 0.25 metres would decrease shore erosion and would also have positive impacts on many variables in Table 13. However, smaller regulation capacity would significantly disturb hydropower production.

All of these improvements in whole lake water level alterations are compared in the summary row of Table 13 as a simple summation of ecological and use parameters separately. However, it should be noted that the use of plus and minus signs gives only a slight indication of the effect and depends on the amount of available variables and in fact many of the impacts are incommensurable. Table 14 includes the summary of the effects of ecological regulation practice (ERP) on biological elements, use and costs. The results of the analysis propose that the lowering of the highest water levels in autumn as well as the change in early winter water level would be the best options to change water level regulation.

On one hand the ERP would have some positive impacts on the littoral ecosystem and fish stocks and on the other hand it has concrete negative impacts on flood protection and particularly on hydropower production. For instance, the losses for hydropower would be over 2 million Euro/year. The positive ecological impacts of ERP are partly uncertain and difficult to quantify. Therefore, it is evident that ERP could not be included in the MEP. However, it might be possible to include some elements of ERP in the MEP, for instance, the lowering of the highest water level.

Table 13. Trend-setting assessment of the impacts of ecological regulation.

	$W_{FEBRUARY}$ (+ 50 cm)	W_{MIN} (+200 cm)	$W_{DURING\ ICE-OFF}$ (+ 50 cm)	$W_{MAX,SUMMER}$ - $W_{MIN,SUMMER}$ (+ 30 cm)	$W_{MAX,\ AUTUMN}$ (-25 cm)
Erosion (Decrease)	0	0	0	+	++
Water quality	0	+/- 1)	0	0	0
Macrophytes	+	+	0	++	+/- 2)
Zoobenthos	+ +	+	+	+	+
Fish fauna	+	+	+	+	+
Ecology	**+4**	**+4 – +2**	**+2**	**+5**	**+5 – +3**
Recreational use	+	+	+	-	+
Fishing	+	+	+	0	0
Floods	0	0/- 3)	0/- 3)	+	+
Hydropower	- -	- - - 4)	-	-	- -
Use	**0**	**0 – -1**	**+1 – 0**	**-1**	**0**

Scale: 0 no impact, +/- slight impact, + + / - - moderate impact + + + / - - - significant impact.

1)in shallow and sheltered bays with long residence time the impact can be negative,

2)if the water level fluctuation during summer time is decreased then also negative impacts can occur,

3)depends on the water conditions, in wet conditions the impact is negative,

4)1.2 mill. Euro/year.

Symbols; $W_{FEBRUARY}$ = water level in the beginning of the February (6.2.), W_{MIN} = minimum water level in spring, $W_{DURING\ ICE-OFF}$ = water level during the ice-off, $W_{MAX,SUMMER}$- $W_{MIN,\ SUMMER}$ = summer water level fluctuation, $W_{MAX,\ AUTUMN}$ = highest water level in autumn.

Other mitigation measures

In addition to alteration of the water level fluctuation regime, there are plenty of different methods representing “all mitigation measures” in Annex V for improving the ecological status of Lake Kemijärvi. Some of the most important and already applied measures are collected in Table 14 with the estimation of effects on use and costs. Determination of MEP in WFD emphasizes ecological continuity and best environmental practice (BEP), which are also estimated separately in the context of different measures (cf. Fig. 15). According to our interpretation the best environmental practice (BEP) is comprised of methods, which do not have harmful impacts on ecology. However, they might have negative impacts on the use of water. In addition to these factors, we also used ecological significance, which is finally the ultimate goal of all improvement measures.

In Lake Kemijärvi the possible mitigation measures include the restoration of important bird areas, protection of erosion shores, removal of tree stumps, recovery of shore meadows and restoration of tributaries. All of these methods except the mechanical recovery of shore meadows have already been applied in Lake Kemijärvi. All other measures except the restoration of bird areas with bottom weirs do not have any effect on use. The large scale protection of erosion shores provides a suitable method, but its ecological significance is very low and large scale use is also non-acceptable, because some plant species highly benefit from erosion shores, which are grounds free of competition.

The most efficient mitigation measure for improving the ecological continuity in the Lake Kemijärvi area is the **restoration of tributaries;** most of the tributaries are dredged for timber floating and also siltation has changed the spawning grounds of salmonids. The restoration may locally have significant positive impacts on fish stocks. However, more information of the current status of tributaries and migrations of fish is needed in order to assess the impacts of restoration on, e.g., whitefish or brown trout stocks in Lake Kemijärvi.

The water level fluctuation can be decreased in some sheltered bay areas by constructing **bottom weirs** (Table 14). The effect on ecological status as well as use depends largely on the upper level of the weir. The ecological effects are local and partly unclear, but positive impacts have been observed in zoobenthos. Large ice-sensitive species can survive, when the decrease in water level is diminished. However, sometimes it has some negative effects on water quality and during the low water level ecological continuity is not fulfilled if bottom weirs do not include fish ladders.

Other measures to increase ecological potential include the installation of **fish ladders** and fish stocking activities (Table 14). Fish ladders improve ecological continuity, but have a clear negative effect on hydropower production. The ecological efficiency of fish ladders is questionable in the River Kemijoki because there are many sequential power plants. It might be questionable to equip all seven power plants with fish ladders. The benefits of fish ladders depend on the available spawning areas for migrating fish. At least in the lower part of the River Kemijoki spawning areas are deteriorated and impossible to restore, but one of the main tributary the River Ounasjoki is in quite pristine status. Although the River Kitinen is fully developed and the River Luiro is affected by reduced flow due to the diversion of Reservoir Lokka, there is a relatively large natural tributary River Ylä-Kemijoki upstream to Lake Kemijärvi. It is in pristine condition and offers a relatively good spawning area for migratory fish.

Fish stocking is another very common mitigation measure in Finland. In Lake Kemijärvi the annual value of the stockings, which are carried out to compensate the adverse impacts of regulation, is 75 000 €. According to WFD the focus should be on management strategies, which improve natural reproduction. Therefore, the primary goal should be the enhancement of the natural reproduction of fish stocks. In heavily regulated and constructed watercourses fish stocking is often the only economically feasible way to sustain fish stocks.

It should be noted that fishing and fish stocking have not been taken into account in the WFD. For example, if the status of fish fauna is deteriorated due to the intensive fishing of predatory fish, the ecological status should not be lowered. In fact, it is essential to distinguish the changes caused by ecological factors such as water quality problems and hydro-morphological alterations from the changes caused by fishing or fish stocking.

Comparison of mitigation measures

We found it very difficult to decide whether various mitigation measures belong to MEP or GEP, because there were no general principles for the determination. Based on the principles of Fig. 16 we assessed the needs of different measures for different ecological potential. In the analysis we compared the ecological impacts, impacts on use and costs of each mitigation measure. The results of the analysis are presented in the last row of Table 14. There are four categories:

- measures which are required in the MEP (MEP),
- measures which are required in the GEP (GEP),
- measures which are non-acceptable (NA) due to high costs or significant adverse impacts on use, and
- measures which are not required (NR) in the GEP or MEP due to insignificant impacts on the ecological status.

It should be noted that different methods are analysed independently, although the effect on the ecological status of the lake is a sum of different measures.

Measures that are required in the MEP are:

- Slight or moderate changes in current regulation practice (e.g. lowering the highest water levels) in order to stabilize conditions in the littoral zone.
- Restoration of important bird areas. In spite of the fact that birds do not belong to biological quality elements of WFD, the restoration will have positive impacts on littoral flora and fauna.
- Restoration of tributaries, which might have positive impacts on the natural reproduction of whitefish and brown trout.
- Bottom weirs in some bays to improve conditions in the littoral zone, particularly for ice sensitive zoobenthos and macrophyte species. Bottom weirs can also provide an area for autumn spawning fish eggs and sensitive species of benthic fauna to survive.
- More information on the ecological, economical and social impacts of fish ladders are needed before it is possible to decide whether they are required in the MEP or are not acceptable (NA) measures.

The removal of tree stumps and recovery of shore meadows are considered to be not required measures (NR) in the WFD context. However, the tree stumps significantly harm the recreational use of lake and therefore it would be important to continue shore restoration on a voluntarily basis.

The ecological impacts of the measures included in the MEP are difficult to quantify. It is quite evident that the measures would not have dramatic whole lake scale effects, because the current regulation practise with 7 metres of regulation amplitude and a raised summer time water level still has a major impact on the ecological status of the littoral. However, the changes in the littoral zoobenthos and aquatic macrophytes can be locally significant.

Table 14. Comparison of some mitigation measures in terms of ecological impacts, impacts on use, ecological significance.

	Ecol. Regulation Practice (Table 13)	Restoration of important bird areas	Protection of erosion shores	Removal of tree stumps	Recovery of shore meadows	Restoration of tributaries$^{1)}$	Bottom weirs in sheltered bays	Fish ladders
Macrophytes						0		0
- Vegetation area	+	+ (L)	+ (L)	+ (L)	+ (L)		+ (L)	
- Species composition	0/+	+ (L)	+/- (L)	- (L)	+ (L)		+ (L)	
- Sensitive species	+	+ (L)	+ (L)	- (L)	+ (L)		++ (L)	
Macroinvertebrates				0	0	0		0
- Species composition	0/+	+ (L)	+ (L)				+ (L)	
- Sensitive species	+	+ (L)	+ (L)				++ (L)	
Fish fauna			0		0			
- Species composition	0	+ (L)		0		0/+	0	0/+
- Age structure/ reproduction	+	+ (L)		- ?		++	+	+
Use								
- Hydro power	- -	-	0	0	0	0	-	-
- Flood protection	-	0	0	0	0	0	0/-	0
- Recreational use	++	++	++	+++	+	+	+	+++
and fishing	+	0	+++	-	0	0	0	0
- Shore erosion								
Costs								
- Construction	0	- -	- -	- -	- -	- ?	- -	- - -
- Use	0	0	0	0	0	0	0	-
Ecological continuity	+	+	0	0	+	++	-	+++
Best env. practice	yes	yes	no?	yes	yes	yes	yes	yes?
Ecological significance	*	*	0	0	0	**	*	*
Rating of measure	MEP$^{2)}$	MEP	NR	NR	NR	MEP	GEP/MEP	NA/MEP

0 no impact, +/- slight impact, ++ / - - moderate impact, +++ /- - - significant impact) and costs (- low costs, - - moderate costs, - - - high costs,
(L) = only of local importance,
$^{1)}$ = (impacts in L. Kemijärvi), $^{2)}$ = Only such changes which do not have significant adverse impacts on use. Refer to the text for details.

8.3 Comparison with Comparable Water Body

The natural status of Lake Kemijärvi was applied as the reference status because both typology and classification systems were under development during the time of this case study. Furthermore, Lake Kemijärvi represents a very rare lake type in Finland; a large lake with a very large drainage basin with a very low lake percentage. Consequently, it is very difficult or even impossible to find a good reference lake for it and, therefore, the comparison to natural status is well grounded. The REGCEL water level analysis tool was applied to provisionally assess the impacts of current regulation on biological quality elements. Results of water level analysis have already been described in previous chapters.

8.4 Discussion and conclusions

Discussion and conclusions of MEP are combined with discussion of GEP in Chapter 9.3.

Definition of Good Ecological Potential

9

9.1 Determination of Good Ecological Potential

GEP represents an ecological status that is discriminated from MEP by the "slight deviation" in the values of the relevant biological quality elements (Figs. 15-16). General, physicochemical and hydro-morphological conditions are appropriate to ensure GEP. Synthetic and non-synthetic pollutants are as low as in a water body, which is not modified. As discussed earlier in Chapter 8, the slight deviation between MEP and GEP must be decided case-by-case.

The crucial question is what does slight deviation mean here? The ecological quality ratio scale (Annex V, 1.4.1) which is divided into five classes suggests that the slight deviation could mean a 20-40 % difference in the values of biological quality elements between MEP and GEP. As described in Chapter 8 the ecological status of Lake Kemijärvi in MEP would not differ significantly from its current status on the whole lake scale. Therefore, we can easily conclude that Lake Kemijärvi is in good ecological potential at the moment. It should be noted that various mitigation measures have been carried out in order to improve the ecological status as well as the conditions for recreational use and fishing in Lake Kemijärvi.

In Table 14 effects on ecology and uses are summarized. In our case study GEP didn't include any changes in regulation practice due to significant effects of use or high costs. However, the hydro-morphological conditions ensure that GEP can also include changes in regulation practise, if regulation is managed in an improper manner. As explained earlier, this was not the case in Lake Kemijärvi, where the operational use of the water course is well planned and based on hydrological forecast data.

Another critical issue is the need of fish stocking for GEP. There is a clear indication that lake trout stocking has not been very successful due to downstream migration. In addition, the efficiency of whitefish stocking has been relatively poor probably due to lowered production of the lake. On the other hand it is one of the most concrete compensatory actions to reduce the harmful effect of water level regulation and is therefore a strict requirement of fishermen.

9.2 Identification of Measures for Protecting and Enhancing the Ecological Quality

9.2.1 Basic Measures

Not relevant in our study.

9.2.2 Supplementary Measures

Not relevant in our study.

9.3 Discussion and Conclusions

Regulation of Lake Kemijärvi started more than 37 years ago. It is well known that vegetation succession and stabilisation after water level regulation will take place in a few decades. Stabilisation of the littoral zone is easy to predict if the erosion of it is neglected. As noted in the follow up of littoral vegetation, there were hardly any changes in species composition in sheltered areas from the years 1983 to 1998, but significant changes were observed on open shores (Hellsten et al. 1999). It indicates the unstable nature of erosion shores, where the stability depends on recent high water levels and erosion processes related to it. However, it is quite obvious that if the current regulation practice will continue no major changes in the littoral zone will happen.

It is important to notice that the measures included in the GEP should be critically evaluated and explained, because the GEP is the objective status for heavily modified water bodies. This applies also to MEP because there is only slight difference in ecological status between MEP and GEP. This requires that the costs, benefits, negative impacts, technical feasibility, social acceptance, and cost-effectiveness of various methods should be carefully assessed. The assessments have to be made case-by-case. Nevertheless, there is a great need to compile general principles for the definition of GEP. For instance, there might be cases where slight changes to regulation practices can positively affect the ecological status without causing harm to use. In some cases the original objective of regulation is not anymore important and there exists good possibilities to revise regulation practice. As a conclusion, we suggest that the definition of the measures required in MEP and GEP need the evaluation of current regulation practice and its impacts.

Lake Kemijärvi has been a target of active restoration activities since the beginning of regulation. Several bottom weirs have been constructed and intensive fish stocking has taken place. As shown in previous chapters ecological status is not far from good – many biological quality elements have already reached good status although the general status is probably lower than good. Our analysis of the applicability of various mitigation measures suggests that there are quite a few possibilities to improve the ecological status without causing harm to use or without causing disproportionate costs. Consequently, we propose that the ecological status of Lake Kemijärvi is Good Ecological Potential (GEP).

10

Conclusions, Options and Recommendations

10.1 Conclusions

The case studies of HMWB projects started earlier than other projects related to the implementation of the WFD on a European and national scale. Consequently, there were no answers for many questions during the time of the project. The lack of typology and classification systems forced us to do numerous assumptions and simplifications in our case study. The papers compiled by the project managers and presentations and discussions in HMWB working groups have been very useful and greatly supported our work. From our point of view the case study approach was good and obviously the only way to concretely figure out the various tasks of the WFD in heavily modified water bodies.

Our experiences propose that it is important to define general principles for many issues in the WFD. On the other hand, the identification of pressures, designation process and definitions of MEP and GEP should be retained flexible enough to take site-specific characteristics into account.

Clarifications are needed in the following issues:

- IDENTIFICATION OF PRESSURES
  - Which pressures are significant and should be taken into account? In practice it is not possible to identify every single morphological change.
  - What is the reasonable scale to identify pressures? From our point of view the scale should be flexible and take into account the local condition.
- IDENTIFICATION OF A WATER BODY
  - What is the reasonable size of the water body? We suggest that the water body should be large enough in order to form a reasonable management unit. For instance, it is reasonable to consider sequential run-of-river impoundments as a single water body although there may be slight differences in ecological conditions (see chapter 4.4.).
- ASSESSMENT OF THE ECOLOGICAL STATUS
  - What kind of biological quality factors are used in the assessment of ecological status? If the factors sensitive for water level regulation (e.g. littoral zoobenthos, extension of Cares-zone) are chosen, the impacts of regulation will have a more significant impact on the ecological status. We propose that the use of sensitive species is justified if they are functionally significant and typical for the specific water body type.
  - How is the biological status assessed from the status of macrophytes, macroinvertebrates and fish fauna? Is it minimum or average of those factors?
  - What is the correct interpretation for terms in Annex V, e.g., “differ moderately from type-specific conditions”?

- DESIGNATION PROCESS
  - What is the importance of provisional designation? Does it matter if we have underestimated or overestimated the number of probably heavily modified water bodies in the provisional designation phase or do we arrive to the same conclusions in the final designation notwithstanding the result of provisional designation?
  - What does the significant adverse impact mean?
  - How do we take into account that the price of electricity varies in different countries and therefore the value of significant impact fluctuates depending on case?
  - A directive for promotion of electricity produced from renewable energy sources has been launched in fall 2001. The aims of that directive are partly opposite to the WFD. How are the objectives of these two directives reconciled in watercourses where the production of hydropower is an important use?
  - Should some of the decisions related to designation be made on a national level or are they all made at the regional level? For instance, if the WFD changes regulation practices in many water bodies it can indirectly affect CO_2-emissions and thus be contradictory to the national need to reduce emissions.
- DEFINITIONS OF THE ECOLOGICAL POTENTIAL
  - Does the term "given the physical conditions" in Annex V really mean that mitigation measures considered in setting MEP must not impact the use, which has caused the designation as an HMWB?
  - What does a slight deviation between MEP and GEP mean? Is it 20 – 40 % higher values of biological quality elements in MEP compared to GEP?
  - What are the costs of all mitigation measures in MEP and GEP? Could it be a percentage share of the value of the use?
  - How absolute are the requirements for ecological continuity? Can longitudinal continuity be replaced by a lateral one? Do we have to support fish ladders, although spawning grounds and fish stocks are more easily supported by stocking?

The WFD defines the minimum requirements for the management of heavily modified water bodies. However, nationally it is possible to apply more stringent objectives for ecological status and for required mitigation measures. In Finland, the national legislation makes it possible to revise old regulation permits if the regulation has significant adverse impacts on the aquatic ecosystem or recreational use. However, the changes in regulation practice should not have significant adverse impacts on the original objectives of the regulation. Consequently, many regulation development projects have been carried out during the last decade and in many cases regulation practices have been modified.

10.2 Options and Recommendations

The discussions with Swedish and Norwegian colleagues and the Nordic meeting in Stockholm in 11/2001 have raised the question of a common Nordic approach in the implementation of WFD in heavily modified water bodies. There are lots of similarities especially between Finland and Sweden:

- A large amount of water bodies have to be considered. As a result, there is a need for a pragmatic approach and use of indirect criteria in provisional designation when the biological data is scattered.

- Water level regulations for hydropower and flood protection are the main pressures in many Northern rivers and lakes. The main emphasis in these watercourses should be in hydro-morphological pressures and mitigation measures.
- A substantial spring flood exists in many watercourses due to the melting of snow. The spring flood affects littoral flora and fauna. Especially riparian vegetation (rivers) or littoral vegetation (lakes) are sensitive for changes in the magnitude of the spring flood. Consequently, they are good indicators for ecological status in regulated lakes and rivers.
- Similarities in flora and fauna and in water use makes it possible to use partly the same indicators (sensitive species) when impacts of the pressures are assessed or in the classification of water bodies. Additionally, the same impact assessment methods can be applied, for instance, water level analysis tools.
- The relatively good status of watercourses compared to lakes and rivers in Central Europe.

The following questions and issues have the need to be addresses in further discussions:

- Should the same principles in the identification of water bodies in HMWB water bodies be applied in Nordic countries? For example, the size of the water body: is one river reservoir a single water body or do all sequential river reservoirs form one water body?
- Is there a need to intercalibrate the criteria of provisional designation?
- River continuum (e.g. fish ladders) should be considered critically in some cases due to very limited reproduction areas available and increased fish disease risks especially in cases where spawning areas are deteriorated and impossible to restore.

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Documentation page

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Title of publication	Heavily Modified Waters in Europe A Case Study of Lake Kemijärvi, Finland
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Abstract	The Water Framework Directive (WFD) allows EU Member States to identify surface water bodies which have been physically altered by human activity as heavily modified water bodies (HMWB) under specific circumstances. As part of the EU WFD Common Implementation Strategy (CIS), a working group (2.2) has been established to develop guidance on the process of HMWB designation. Working group selected thirty-four case studies from ten different Member States and Norway a draft provisional identification and designation process for heavily modified water bodies was tested supported by reference to the guidance papers. Finnish case study was Lake Kemijärvi, which is a large regulated lake which is regulated for hydropower and flood protection purposes with regulation amplitude of 7 meters. Lake Kemijärvi case study followed general guidelines, which were identification of water body, determination of pressures, provisional identification as HMWB, determination of ecological status and designation as HMWB and finally definition of ecological potential. Despite of relatively good data for designation, it was found that there were lack of ecological data and especially reference lakes. Moreover, the procedure seemed to be relatively complicated and some terms such as ecological potetential were very difficult to determinate. Final results of the study was quite clear - Lake Kemijärvi is obviously heavily modified water body. Results are largely applicable in other regulated lakes in Finland
Keywords	EU Water Framework Directive, heavily modified waterbodies, water level regulation, hydropower production, Lake Kemijärvi
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Tekijä(t)	Mika Marttunen ja Seppo Hellsten		
Julkaisun nimi	Vesipolitiikan puitedirektiivin soveltaminen Euroopan voimakkaasti muutetuissa vesimuodostumissa - Kemijärven tapaustutkimus (Heavily Modified Waters in Europe - A Case Study of Lake Kemijärvi, Finland)		
Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavana myös Internetistä: www.ymparisto.fi/julkaisut		
Tiivistelmä	Euroopan Yhteisöjen Vesipolitiikan Puitedirektiivi (VPD) astui voimaan joulukuussa 2000. VPD:n täytäntöönpanoa tukeva työryhmä (CIS) on asettanut kymmenen työryhmää, joiden tehtävänä on luoda ohjeistoja erityisesti tulkinnanvaraisten VPD:n kohtien selkiinnyttämiseksi. Erään näistä kymmenestä ryhmästä muodosti voimakkaasti muutettujen vesistöjen nimeämisen työryhmä. Työryhmätyöskentelyn perustan muodostivat 11 Euroopan valtiossa tehdyt 34 tapaustutkimusta, joista kolme koski järviä. Suomen tapaustutkimuksen kohde oli Kemijärvi (288 km^2), joka seitsemän metrin säännöstelyvälillään on Suomen voimakkaimmin säännöstelty luonnonjärvi. Tapaustutkimuksessa noudatettiin tapaustutkimuksille laadittuja ohjeita. Siinä käytiin läpi kaikki keskeiset voimakkaasti muutettuja vesiä koskevat työvaiheet: vesimuodostuman rajaus, paineiden tunnistaminen, alustava nimeäminen, ekologisen tilan arviointi, varsinainen nimeäminen ja ympäristötavoitteiden määrittäminen. Tapaustutkimuksen toteuttamista vaikeutti mm. annettujen ohjeistojen puutteellisuudet erityisesti tilan arviointiin ja ympäristötavoitteiden määrittämiseen, tapaustutkimuksen aikainen ajankohta suhteessa tyypittelyä ja luokittelua koskevaan kansalliseen valmisteluun sekä osin myös biologisen aineiston niukkuus. Tarkastelussa Kemijärvi arvioitiin voimakkaasti muutetuksi. Hankkeessa sovellettua lähestymistapaa ja menetelmiä voidaan pääosin soveltaa myös muissa säännöstelyissä järvissämme.		
Asiasanat	Vesipolitiikan puitedirektiivi, vesistöt, säännöstely, voimakkaasti muutetut vesimuodostumat, vesivoimantuotanto, Kemijärvi		
Julkaisusarjan nimi ja numero	Suomen ympäristö 630		
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Projektihankkeen nimi ja projektinumero	Vesipolitiikan puitedirektiivin soveltaminen Euroopan voimakkaasti muutetuissa vesimuodostumissa - Kemijärven tapaustutkimus (nro: 310019)		
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Författare	Mika Marttunen och Seppo Hellsten
Publikationens titel	Tillämpling av ramdirektivet för vattenpolitiken i kraftigt modifierade vattenförekomster i Europa - fallstudie rörande Kemi träsk. (Heavily Modified Waters in Europe - A Case Study of Lake Kemijärvi, Finland)
Publikationens delar/ andra publikationer inom samma projekt	Puplicationen finns tillgänglig på Internet: www.miljo.fi/publikationer
Sammandrag	Europeiska gemenskapernas direktiv (2000/60/EG) om upprättande av en ram för gemenskapens åtgärder på vattenpolitikens område trädde i kraft i december 2000. Den arbetsgrupp (CIS) som stöder implementering av ramdirektivet har tillsatt tio arbetsgrupper vilka har som uppgift att upprätta regelverk för att särskilt klarlägga de flertydliga punkterna i direktivet. En av dessa tio grupper bestod av en arbetsgrupp för definition av vattendrag som modifierats kraftigt. Utgångspunkten för arbetet i denna arbetsgrupp utgjordes av 34 fallstudier i 11 europeiska stater, varav tre gällde sjöar. Fallstudien i Finland gällde Kemi träsk (288 km^2), som med sin regleringsintervall på sju meter utgör den kraftigast reglerade sjön i naturtillstånd i Finland. Vid fallstudien efterföljde man för fallstudier uppgjorda anvisningar. Man gick genom samtliga viktiga arbetsskeden som berörde de kraftigt modifierade vattendragen: avgränsning av vattenförekomsten, fastställande av påverkan, preliminär definition, bedömning av det ekologiska tillståndet, slutlig definition och identifiering av miljömål. Förverkligandet av fallstudien försvårades bland annat av brister i de angivna föreskrifterna speciellt för utvärdering av tillstånd och identifiering av miljömål, den tidiga tidpunkten för fallstudien i relation till den nationella beredningen av typindelning och klassificering, samt delvis av det otillräckliga biologiska materialet. I studien bedömdes Kemi träsk vara kraftigt modifierat. Det tillvägagångssätt och de metoder som projektet tillämpade kan till huvuddel även tillämpas i våra övriga reglerade sjöar.
Nyckelord	Ramdirektiv för vattenpolitiken, vattendrag, reglering, kraftigt modifierade vattenförekomster, vattenkraftsproduktion, Kemi träsk
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Heavily Modified Waters in Europe

European Water Framework Directive (WFD) have significant impacts on the water resources management and monitoring all over the Europe. As a part of developing guidance on the process of designation of heavily modified water bodies thirty-four case study projects, carried out in the member states and Norway. Lake Kemijärvi, which is the most heavily regulated natural lake in Finland, was target of Finnish case study. In the case study different tasks of WFD has been carried out, analysed and discussed. As a consequence of analysis lake Kemijärvi was designated as heavily modified.

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