Finnish Environment Institute Mimeographs

336

Climate change adaptation for hydrology and water resources

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FINADAPT Working Paper 6

FINNISH ENVIRONMENT INSTITUTE

CLIMATE CHANGE ADAPTATION FOR HYDROLOGY AND WATER RESOURCES

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FINADAPT WORKING PAPER 6

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This publication should be cited as:

Silander, J., Vehviläinen, B., Niemi, J, Arosilta, A., Dubrovin, T., Jormola, J., Keskisarja, V., Keto, A., Lepistö, A., Mäkinen, R, Ollila, M., Pajula, H., Pitkänen, H., Sammalkorpi, I., Suomalainen, M. and Veijalainen, N. 2006. Climate change adaptation for hydrology and water resources. FINADAPT Working Paper 6, *Finnish Environment Institute Mimeographs 336*, Helsinki, 52 pp.

Preface

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"[1]. The IPCC lists two reasons why adaptation is important in the climate change issue. First, an understanding of expected adaptation is fundamental in evaluating the costs or risks of climate change. Second, adaptation is a key response option or strategy, along with mitigation. Even with reductions in greenhouse gas emissions, some climate change is regarded as inevitable, and it will be necessary to develop planned adaptation strategies to deal with the associated risks as a complement to mitigation actions.

In Finland, there has been substantial progress during the past decade in investigating the potential impacts of climate change on natural and human systems. In contrast, there has been much less attention paid to adaptation. This was recognised by the Finnish Parliament as early as 2001, when it recommended that a separate programme for adaptation to climate change be initiated. As a result, a task force co-ordinated by the Ministry of Agriculture and Forestry completed Finland's first National Strategy for Adaptation to Climate Change in 2005.[2]

At about the same time as the Strategy document was being drafted, a research consortium named FINADAPT also began its work. The goal of the consortium, involving 11 partner institutions co-ordinated by the Finnish Environment Institute, was to undertake an in-depth study of the capacity of the Finnish environment and society to adapt to the potential impacts of climate change. FINADAPT was funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment. It comprised 14 work packages (WP) covering: 1) co-ordination, 2) climate data and scenarios, 3) biodiversity, 4) forests, 5) agriculture, 6) water resources, 7) human health, 8) the built environment, 9) transport, 10) energy infrastructure, 11) tourism and recreation, 12) economic assessment, 13) urban planning, and 14) a stakeholder questionnaire. The primary objective of FINADAPT was to produce a scoping report based on literature reviews, interactions with stakeholders, seminars, and targeted research.

This report, an output from work package 6, presents a wide-ranging review of current knowledge concerning adaptation to climate change for hydrology and water resources in Finland. It builds on earlier impact studies relating to climate change and hydrology, taking in issues of water supply and wastewater, flood risk, water course regulation, hydropower generation, dam safety, drainage and irrigation, drought, and restoration of inland waters. It also addresses water quality of inland and coastal waters, an issue hitherto little researched in Finland.

Timothy Carter, Consortium Leader
Helsinki, December 2005

[1] IPCC, 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds)]. Cambridge University Press, Cambridge and New York, p. 982.
[2] MMM, 2005. *Ilmastomuutoksen kansallinen sopeutumisstrategia* (Finland's National Strategy for Adaptation to Climate Change) [Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatuki, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (eds)], Ministry of Agriculture and Forestry, Helsinki (available in Finnish, 276 pp., Swedish 212 pp. and English, 280 pp.) http://www.mmm.fi/sopeutumisstrategia/

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CLIMATE CHANGE ADAPTATION FOR HYDROLOGY AND WATER RESOURCES

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Executive Summary

Hydrology: The most important effect of climate change on hydrological regimes in Finland is the change in seasonal distribution of runoff. Winter runoff is expected to increase considerably due to an increase in snowmelt and rainfall, while spring floods are estimated to decrease in southern Finland. In northern Finland spring floods are expected to increase during the next few decades due to increased snowfall, but then to decline over the longer term with continuous warming. Yearly runoff is estimated to change from –5% to 10%. Decreases are predicted for catchments with a large lake surface which enhance lake evaporation; increases are through winter runoff. In winter excess water from snowmelt and rainfall can cause winter floods, especially large central lakes Saimaa, Päijänne and Näsijärvi will be more frequently flooded. Extreme runoff events are projected to be more frequent due to increased maximum precipitation.

Quality of surface waters: Floods and droughts will potentially be increased due to climate change. During low flows, increased concentrations of bacteria, harmful algae and toxins are common. High flows and intense rainfall increase soil erosion, chemical leaching, urban and livestock wastes and nutrients from catchments into watercourses and coastal waters. Adaptation includes changes in land use and cultivation practices, changes in monitoring and improved planning for severe floods and drought periods. Effects of climate change in lakes and the Baltic Sea are either direct (stratification, currents, biological productivity) or indirect due to changes in catchment. In coastal waters, predicted increases of nutrient leaching enhance eutrophication. Areas affected are on the southern and south-western coasts, due to intensive cultivation and lack of lake retention in coastal basins. The most important measure for adaptation is a reduction in nutrient loads from diffuse sources and from the largest point sources.

Groundwater is classified high class household water in Finland. If the length of dry periods in summer increases in southern Finland, groundwater discharges will be reduced and this may also lead to shortage of dissolved oxygen, high concentrations of dissolved iron, manganese and metals in the groundwater. Other harmful substances resulting from shortage of dissolved oxygen may be ammonium, organic matter, methane and hydrogen sulfide gases causing bad taste and smell. In wintertime increasing precipitation and snowmelt will produce fresh and oxygen rich groundwater. Thin soil layers add the risk of groundwater contamination by bacteria during floods. Hydrological, chemical and biological processes connected to groundwater are often not sufficiently known, and more research of these processes is needed.

Water supply and waste water: The changing climate is not likely to introduce new types of threats for water supply and wastewater systems. However, the present problems related to climate will become more frequent. The main adaptation measures to tackle the problems are increased co-operation between water utilities, alternative reserve systems, expansion of networks to rural areas, enhancements in water purification processes, replacing combined sewers with separate sewers and repairing network leaks. Small water utilities and wastewater systems with combined sewers are most vulnerable to climate-related problems.

Flood risk management: Adaptation should be easier if watercourses are considered as entities, where the threat of floods can be prevented primarily by improving watercourse regulations and by increasing the number of designated areas and preserved areas for flood water. Those areas also help to sustain the water balance and water quality in settled and rural areas. Recommendations for the lowest building levels should be re-considered on a regular basis, which could require the construction of levees and permanent pumping devices, or at least changes in land use patterns, especially in some seashore areas. In some areas movable flood protection structures and equipment should be collected in depots, e.g. in the city of Pori. At the minimum, in urban areas storm water guidelines need to be updated and the impermeable areas properly managed. Shorter observation and forecast periods are also needed, especially in flash flood situations, to improve flood preparedness.

Research is needed to assess changes in flood with a current recurrence time of 20-250 years, to enable proper adaptation measures in water reservoir regulation, flood control and mitigation and to determine the lowest recommended building levels. Non-structural measures to manage extreme and flash floods should also be studied.

Water course regulation: Frequent winter floods and a smaller amount of snow call for free storage capacity in reservoirs in winter and less storage capacity in spring in southern Finland. In northern Finland storage capacity is still needed for snowmelt floods. To account for longer and dry summers, reservoirs should be filled up in spring in southern Finland. Better operative use of regulated reservoirs, more accurate and frequent observations and forecasts and even reconstruction of dam outlets are needed. Roughly estimated, more than half of the 220 regulation permissions require adjustment.

Hydroelectric power: Hydroelectric power generation is estimated to increase by 0-10% up to the 2030s, due to large winter discharges. The increase is due, in part, to decreased spill-off in spring with smaller floods. Conversely, higher water levels in the central lakes as Saimaa, Päijänne and Näsijärvi at winter can increase the spill-off. This winter spill-off can be reduced by increased turbine capacity or by changes in reservoir regulation.

To increase continuity and ecological productivity of rivers for migrating fish, a part of the increased discharges should be used as permanent and temporary spill-offs, leading into specially created fish bypasses and side channels.

Dam safety: Design precipitation (recurrence time 1 000-10 000 years) is estimated to increase by up to 40-60%, which would cause problems for dams below small catchments (10-500 km^2). Increased monthly or seasonal precipitation together with winter snowmelt are reasons for increased design floods for dams below large catchments (over 10 000 km^2). In catchments with large lake systems late summer, autumn or winter floods will be the design

floods in the future. Adaptation measures such as changed reservoir regulation, increase of outflow and storage capacity can be used. Improved observation and warning systems, more accurate forecasting and improved readiness for mitigation actions and repairs are also needed.

Drainage and irrigation: Drainage channel design should be based on rainfall floods instead of snowmelt floods in the future. The drainage demand and condition of drainage infrastructure should be assessed to determine the need for changes in drainage infrastructure. Construction of drainage channels should be carried out sustainably, including the use of natural flood retention possibilities. The demand for irrigation water should be determined and possibilities for water reservoirs and water transfer should be studied.

Surface water restoration: Climate change increases external and (indirectly) internal nutrient loading and turbidity in lakes, coastal water areas and rivers. Blooms of cyanobacteria, overgrowth of littoral macrophytes, populations of cyprinid fish and hypoxic and anoxic layers in stratified water bodies are likely to increase. Aeration, management of macrophytes and mass removal of cyprinids could provide ways to prevent the unfavorable effects of climate change on Finnish lakes in addition to measures reducing the external loading from the drainage area. Cost effective implementation and impacts of different management or restoration methods and their combinations would be an important objective for future experimental and modelling research.

The goals of river restoration for fishery, recreation and ecological diversity should be combined with the increasing need for flood control and water purification. New flood areas and wetlands should be created, taking into account bird habitats and performance for sedimentation and nutrient removal, as well as urban storm water management. Wetlands also serve for balancing hydrology and low discharges in drought periods in summer, which is essential for fish and recreation. River restoration and management methods, applying ecohydraulics, need to be investigated, to define the discharge performance of vegetated flood areas in summer floods and to diversify river corridors and the meandering course and structure of rivers and small streams for fish.

1. Introduction

Finland is located in a transition zone between a continental and maritime climate, and belongs mostly to the boreal zone. The influence of the Baltic Sea and the Gulf Stream moderates the climate compared to more continental locations at the same latitude to the east.

Finland's mean precipitation is about 660 mm and from this amount, 340 mm is evaporated, while 320 mm flows to the seas or passes over the national borders. The annual mean discharge of Finnish rivers is about 3400 m^3s^{-1}.

Lakes cover some 33 500 km^2 (about 10%) of the total area of Finland. A survey by Raatikainen and Kuusisto (1990) showed that the number of water bodies exceeding 500 m^2 (0.0005 km^2) totalled 188 000. Of these about 56 000 have an area greater than 10 000 m^2 (0.01 km^2) and about 2600 have an area greater than 1.0 km^2. Lakes are typically shallow, with an average depth of about 7 m, often forming lake chains. The majority of large lakes are in the Lake District in the central and eastern part of the country. The total volume of lakes is about 235 km^3 and the average residence time about two years. About one third of the lake area is regulated. There are 647 rivers in Finland, with a drainage basin area of over 100 km^2 and with at least 10 km of channel uninterrupted by lakes. The total length of these rivers is about 20 000 km. There are 12 rivers with a drainage basin greater than 10 000 km^2 and 295 rivers with a drainage basin between 100 and 200 km^2. If rivers with smaller drainage basins were included in the calculation the number of rivers would be considerably higher. Discharges of rivers vary widely, being highest during the spring and autumn high flow.

The area of the Baltic Sea (BS) is 415 266 km^2. The basic nature of the sea is estuarial, due the strong river water inflow and the very limited input of ocean water through the Danish Straits. The Baltic Sea receives fresh water from a catchment area of 1.7 million km^2, i.e. more than four times the sea area itself. A population of 85 million lives in the catchment of Baltic Sea. Southern parts of the catchment, in particular, are intensively cultivated and all the countries located in the catchment are highly industrialized. This means that, in addition to the direct impacts on the sea, all extensive changes in the catchment, caused either by climate change or some other factor, will have their impacts on the state of the Baltic Sea. The estuaries along the Finland coasts are relatively shallow, and the coastline is characterized by a complex topography.

This report contains three main sections. The first section (2) describes changes in the hydrology of inland waters. The second section (3) describes changes in water quality; potential impacts, adaptation and R&D needs under future climate change. The final section (4) presents a review and analysis of the current understanding of the potential impacts of climate change and adaptation measures needed in the field of water resource management. The executive summary summarizes key findings and recommendations for adaptation to future threats arising from climate change.

2. Effects on the hydrological cycle – inland waters

Suomalainen, M., Vehviläinen. B., Veijalainen, N., Lepistö, A. and Mäkinen, R.

2.1. Temperature and precipitation

The FINADAPT climate scenarios (Carter et al. 2005) project that annual precipitation in Finland will increase by between 10 and 30% by the 2080s relative to 1971-2000. The change in winter is estimated to be higher than this, by up to 55%. Most of the scenarios indicate an increase in precipitation in all seasons, but some scenarios show that the summers can be somewhat drier than at present. All scenarios also show growth in the big rainfall events. Regardless of season, the maximum 1-day precipitation increases around 20-30%.

The effects of climate change on hydrological conditions have been estimated before in two large projects, SILMU (1990-1995) (Vehviläinen and Huttunen 1997) and ILMAVA (2002) (Venäläinen et al. 2004). The scenarios of annual and seasonal temperature and precipitation changes are compared in Table 1. Annual changes in the FINADAPT A2-scenario are slightly bigger than in the SILMU and ILMAVA A2-scenarios. Changes in the B-scenarios are very similar to each other. The results of ongoing projects Climate and Energy (CE) and FINESSI will be reported in their own publications in 2006, once the projects have been completed. Table 1 shows the temperature and precipitation changes associated with the CE-project scenarios RCAO-H-A2 and RCAO-E-A2, which correspond to scenarios from Rossby Centre's RCAO regional climate model with boundary conditions from GCM's HadAM3H (H) and ECHAM4/OPYC3 (E) with emission scenario A2.

Table 1 Comparison of climate change scenarios used in different hydrological impact studies in Finland.

	Temperature change (per decade)		**Precipitation change (per decade)**	
Project	Annual	Seasonal	Annual	Seasonal
SILMU Central scenario	+ 0.4 °C	Winter: + 0.6 °C Summer: + 0.3 °C	+ 1%	Winter: + 2% Summer: + 1%
ILMAVA HadCM3-A2	+ 0.4 °C	Winter: + 0.6 °C Summer: + 0.3 °C	+ 1.2%	Winter: + 2% Summer: + 1.3%
ILMAVA HadCM3-B2	+ 0.3 °C	Winter: + 0.4 °C Summer: + 0.2 °C	+ 1.5%	Winter: + 0.7% Summer: + 3%
FINADAPT Composite-A2	+ 0.5 °C	Winter: + 0.65 °C Summer: + 0.35 °C	+ 1.4%	Winter: + 2.2% Summer: + 0.4%
FINADAPT Composite-B1	+ 0.3 °C	Winter: + 0.45 °C Summer: + 0.25 °C	+ 1.0%	Winter: + 1.3% Summer: + 0.5%
CE RCAO-H-A2	+ 0.4 °C	Winter: + 0.4 °C Summer: + 0.45 °C	+ 1.4%	Winter: + 2.3% Summer: + 0.5%
CE RCAO-E- A2	+ 0.45 °C	Winter: + 0.6 °C Summer: + 0.3 °C	+ 3.0%	Winter: + 5.1% Summer: + 1.0%

2.2. Snow cover and runoff

The overall trend is that climate change would increase the frequency of warm periods (temperatures above zero) and hence melting of snow during the winter (Figure 1). As the temperature increases the snow cover diminishes in southern Finland and the snow accumulation period will be shortened. In northern Finland, however, the increased winter precipitation can lead to higher maximum snow water equivalent in near-term and also in mid-term period by 2020 and by 2050 respectively (Figure 2).

In south and middle part of the country the maximum snow pack will be diminishing significantly in the mid-term period by 2050, but the variation between years tends to increase northwards. In ongoing FINESSI project sensitivity analysis was conducted by making 120 model runs with various changes in temperature and precipitation. However, the newest model runs from the FINESSI project These model runs suggest that even by 2100 snowy winters will not totally vanish in southern Finland, but there will be 50-70% less snow than nowadays for one or two months. In northern Finland the decrease in maximum snow water equivalent will be less than 20%. Depending on the scenario, the snow pack can even increase slightly (Figure 1).

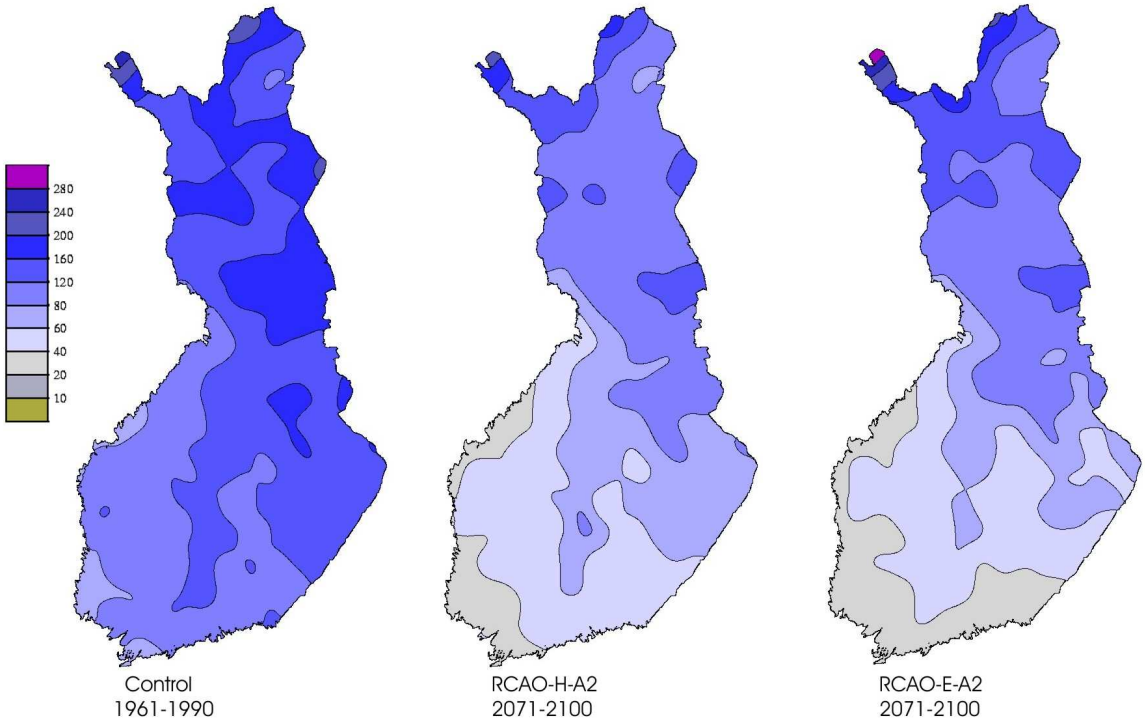

Figure 1. Maximum snow water equivalent (mm) under the present-day, 1961-1990, climate (left) and in 2071-2100 for the RCAO-H-A2 scenario (middle) and RCAO-E-A2 scenario (right). Source: CE-project.

The increase in temperature and precipitation effects both the total annual runoff and the seasonal variation. By 2020 the changes in total annual runoff will be quite minor, only 0-10%, but when the climate change phenomenon reaches the year 2100, the increase in annual runoff varies vastly from 0 to 60% depending on the scenario and more precisely on the changes in precipitation (Figure 3).

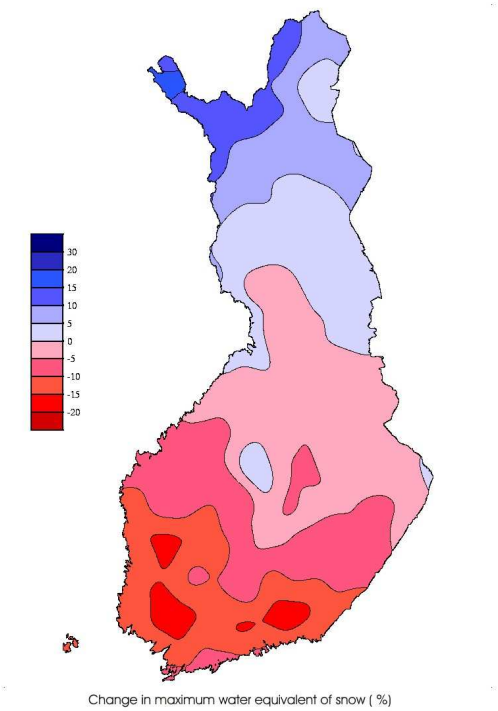

Figure 2. Percentage change of maximum snow water equivalent compared with 1961-1990 for a temperature increases of 1°C and precipitation increase of 20%. Results from the FINESSI-project.

The changes in runoff are very significant at the seasonal level. Climate change leads to increased runoff especially in winter when low evaporation enhances the effect. By 2100 the increase in winter runoff sum can be several hundred percent compared to the present climate (Figure 4). In spring, the snowmelt runoff peak will respectively be smaller and come earlier. Also the spring runoff sums decrease in the long-term period, although there can be a minor increase in northern Finland, because the timing of the runoff peak shifts from the summer season to spring. In summer, both the total evaporation and the risk of heavy rainfall events increase, which means that the summers can become wetter or drier depending on the weather of the year. The long-term effects on summer runoff sums will nevertheless be a decrease. The long-term effects on autumn runoff are difficult to estimate, the increase is between 0-70% depending mainly on the changes in precipitation, but also the dryness or wetness of the previous summer.

2.3. Evaporation, soil moisture and groundwater

The rise in temperature leads to increased evapotranspiration and lake evaporation in spring and early summer. As the soil moisture deficit increases during the summer, the evapotranspiration rate declines reduces considerably. For lake evaporation there are no such limitations, and the lake evaporation remains large also in dry periods. The effects of climate change are therefore major in lake-rich areas.

The largest reductions in summer soil moisture will occur in northern Finland, where summer soil moisture is high at present due to shorter and colder summers with low evapotranspiration. In southern Finland the minimum values of summer soil moisture are already so small that the increased evaporation cannot cause considerable further reduction during dry summers. However, the length of potential dry periods will increase both in southern and northern Finland by 1-2 months due to the earlier onset and later end of summers. The change in maximum soil

moisture deficit by 2070-2100 according to two climate scenarios from CE-project is shown in Figure 5. The larger the maximum soil moisture deficit is, the drier the driest period of the year (usually summer) is.

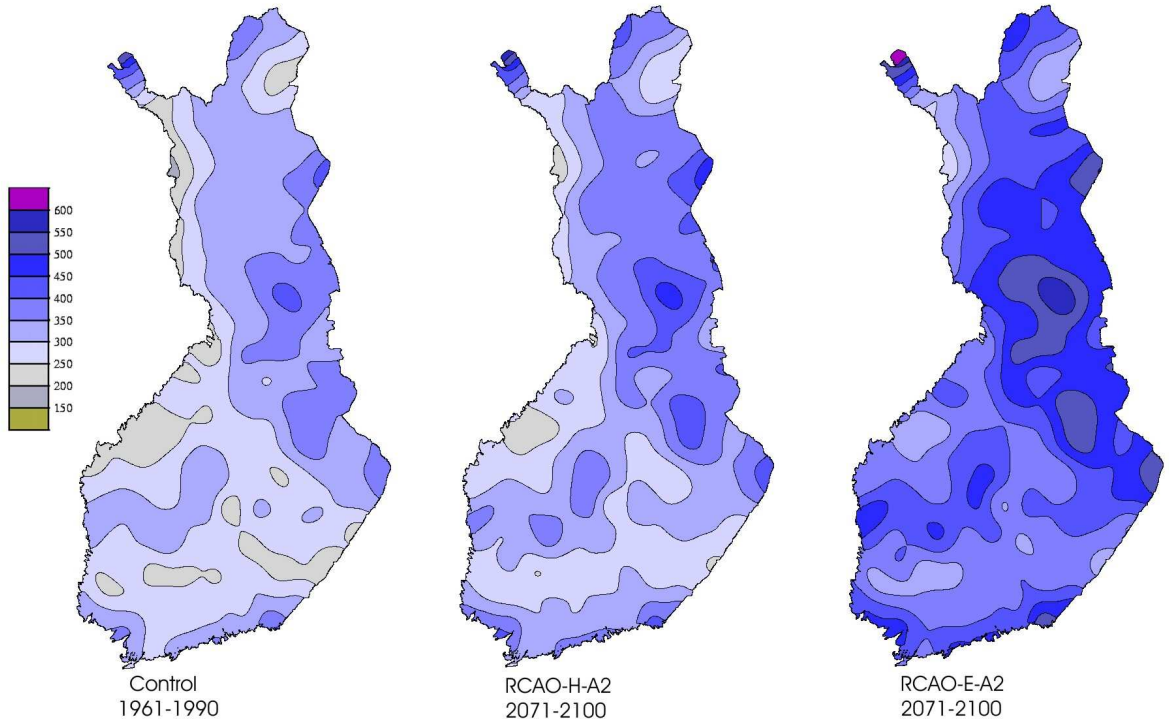

Figure 3. Total annual runoff (mm/yr) in the present-day climate of 1961-1990 (left) and in 2071-2100 for the RCAO-H-A2 scenario (middle) and RCAO-E-A2 scenario (right). Source: CE-project.

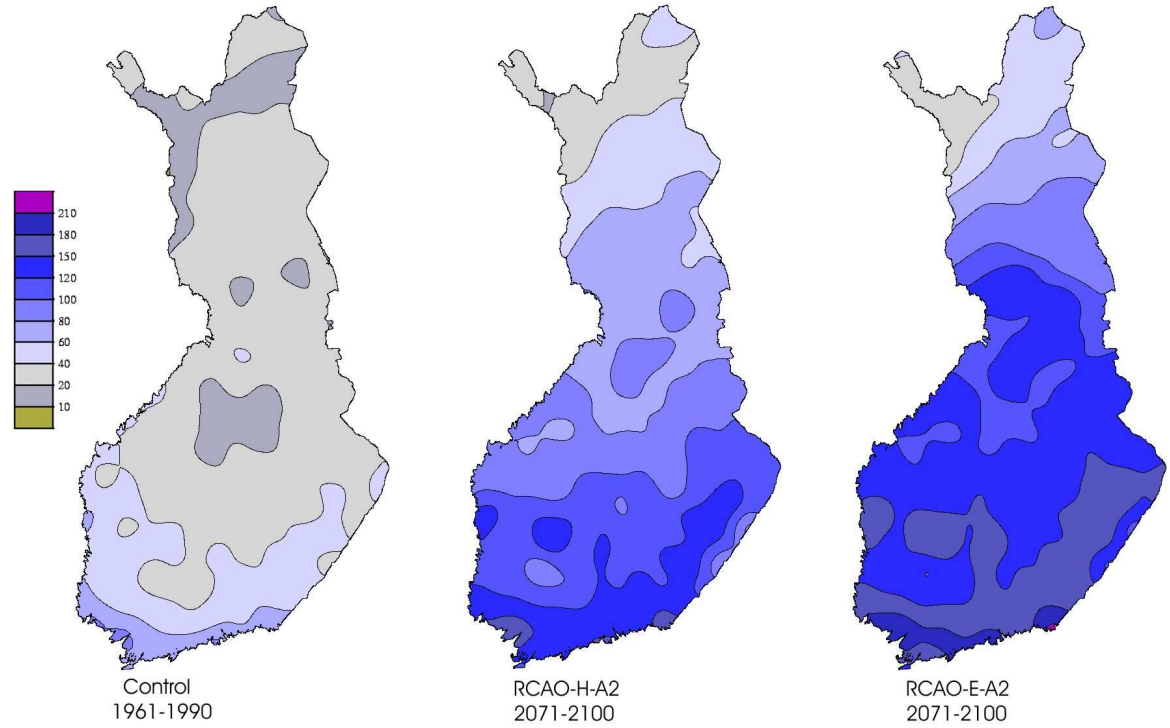

Figure 4. As Figure 3 but for total winter (Dec-Feb) runoff (mm/yr).

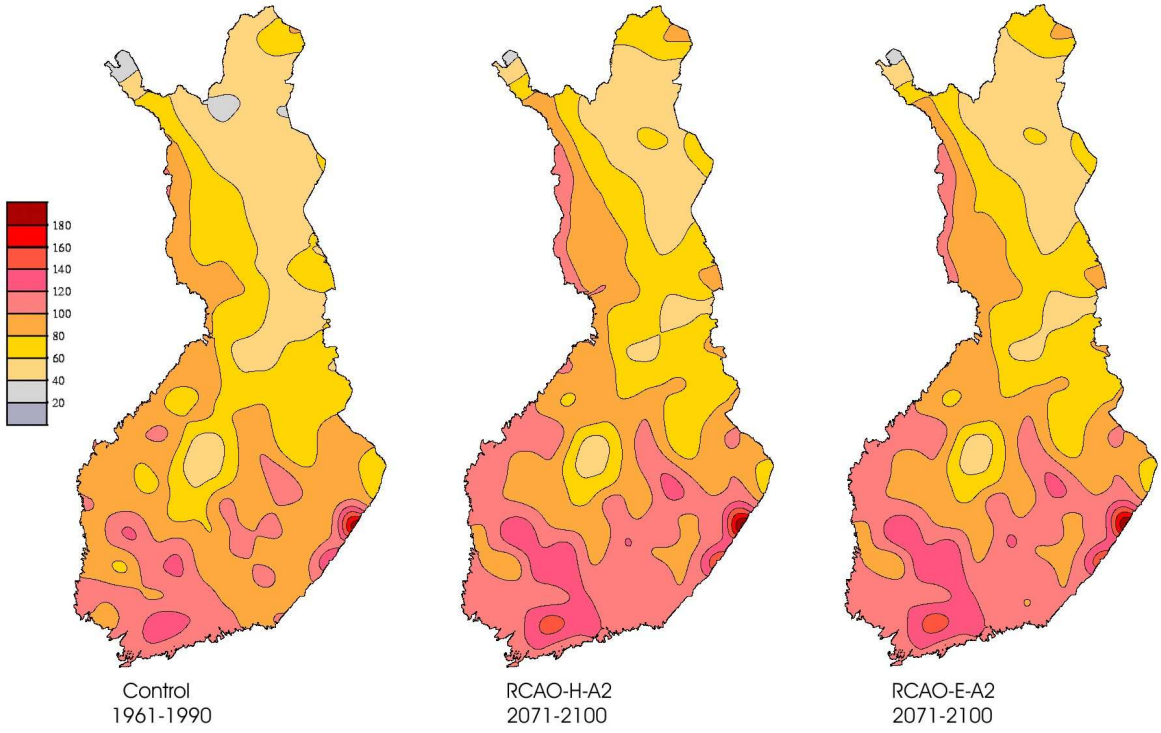

Figure 5. Maximum soil moisture deficit (mm) in the present-day climate, 1961-1990 (left) and in 2071-2100 for the RCAO-H-A2 scenario (middle) and RCAO-E-A2 scenario (right). Source: CE-project.

In the coastal areas of southwest Finland the groundwater level reaches its maximum in the early winter or early spring. This is partly due to the fact that much of the precipitation during the winter comes as rain. The spring comes early and during the summer the groundwater level decreases to a minimum. The precipitation in the late autumn again raises the groundwater level.

2.4. Groundwater fluctuation pattern in Finland

There are different patterns for the annual groundwater level fluctuations in Finland (Figure 6). The variation is controlled by the recharge-discharge mechanisms, which are highly dependent on the climate and vary considerably geographically. The change in the available amount of groundwater is mainly related to variations in precipitation and evapotranspiration. Climate change may modify the regional and seasonal distribution of available water. When the groundwater level is at a high value, the aquifer discharges much more water than when groundwater is at a low level.

In the coastal areas of southwest Finland the groundwater level reaches its maximum in the early winter or early spring. This is partly due to the fact that much of the precipitation during the winter is rain. During the summer the groundwater level decreases to a minimum, while precipitation in the late autumn again raises the level.

In a large part of Finland groundwater fluctuations show two annual maxima and two minima. One minimum occurs in the late winter, just before the melting of the snow cover, and the other minimum occurs in the late summer. One maximum occurs after the snow melts and the other one at the end of the year, due to the autumn precipitation.

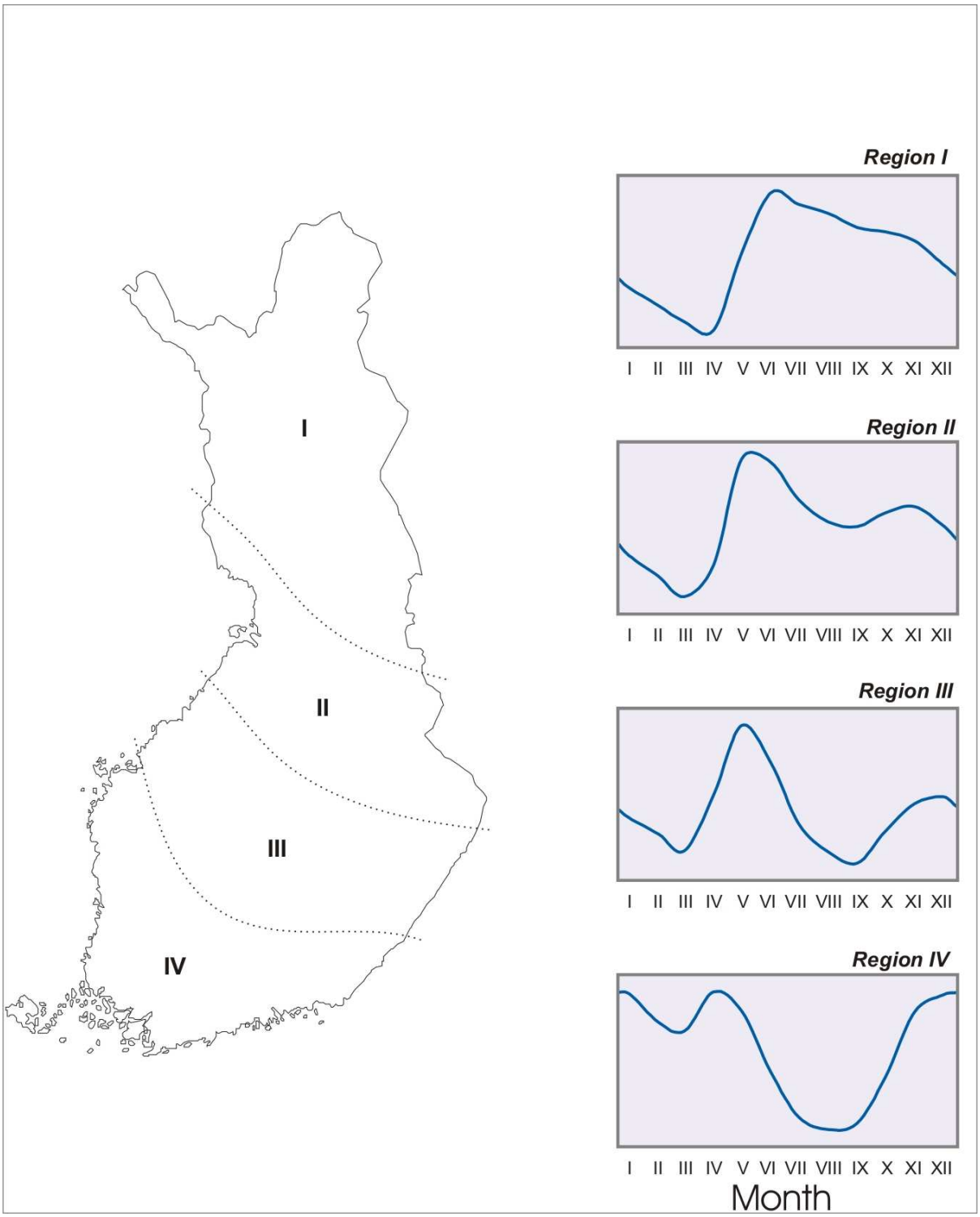

Figure 6. Seasonal patterns of groundwater level fluctuations in different parts of Finland.

In the northern part of Finland the groundwater level has one annual maximum and one minimum. The maximum occurs after the melting of the snow cover in the early summer. The groundwater level declines during the autumn and winter because of the early frost and the fact that the precipitation in the late autumn often is often in the form of snow. The minimum

occurs just before the melting of the snow cover. Under projected warming, the winter will become shorter and spring earlier. During the summer the groundwater level will decreases.

The amplitude of the groundwater level variations will be of different magnitude in different geological deposits, dependent on climate, effective porosity, topography and vegetation. In the deep aquifers there is a time-lag effect, which causes a deviation.

Climate change will affect the groundwater level differently in different parts of the country. The regional pattern of present-day seasonal groundwater levels can be expected to move northeastwards. Overall, higher groundwater levels are anticipated in winter. In summer the length of dry periods will increase, which means lower groundwater levels in summer. It will cause problems to people in rural areas and to small water suppliers.

2.5. River discharges, lake and sea water levels

The discharge of rivers is expected to differ significantly from the current situation under a changing climate. The melting of snow coupled with increased precipitation could double the mean river discharge during winter by 2100. In southern Finland the mean spring flood level will decrease significantly, by as much as 50%, because of the decreased amount of snow, whereas in northern Finland, where the snow pack remains quite large, the mean spring flood level is also expected to decrease, but by only 10-20%. Due to the higher evaporation, the mean summer discharges are prone to decrease. However, the increase in risk of heavy rainfall events is likely to cause river floods in summer as well.

The increase in winter inflows and decrease in spring inflows will change lake water levels differently depending on lake location. Upper basins are estimated to have decreased maximum water levels, because the present floods are caused by snowmelt. However, the central lakes of large catchments like Päijänne and Saimaa are expected to have more frequent winter high water levels and winter floods, due to the abundant rainfall and melt. A diminishing spring inflow can cause difficulties in the filling of lakes in spring and early summer; the risk of spring flood would still exist, but the certainty and predictability of it would be lower. The risk for extremely dry or wet summers increases, which means that water levels and discharges of rivers and lakes can be either lower or higher than nowadays.

It has been estimated, that by the year 2100 the 1-in-100 years flood would increase in southern and middle Finland by about 15% and the 1-in-20 years flood by about 10%. In northern Finland these floods would slightly increase in the near future, but by the end of the century there would be no change in these floods relative to today (Figure 7). In the long run, snowmelt floods decrease while precipitation induced floods increase.

It is likely that the risk of flooding in areas prone to sea level rise is increasing. Land uplift during the 21st century is projected to be about 0,3 m in the city of Helsinki and in some areas even 0,9 m, which will compensate partly or fully the sea level rise, depending on the sea level scenario assumed.

According to the estimates used, climate change would affect flooding so that:

1. In southern and central Finland, snowmelt floods will decrease.
2. In northern Finland, snowmelt floods will increase.
3. In the large central lakes of some river systems, flooding will increase.

4. Large precipitation events are projected to increase, and resulting flood events can be expected to increase in the whole country, accordingly, especially in rivers.
5. Changes of flood risk in coastal areas during this century will depend on the rate of global sea level rise compared to the rate of concurrent local land uplift.

Taken as a whole, floods are expected to increase rather than decrease during the 21st century.

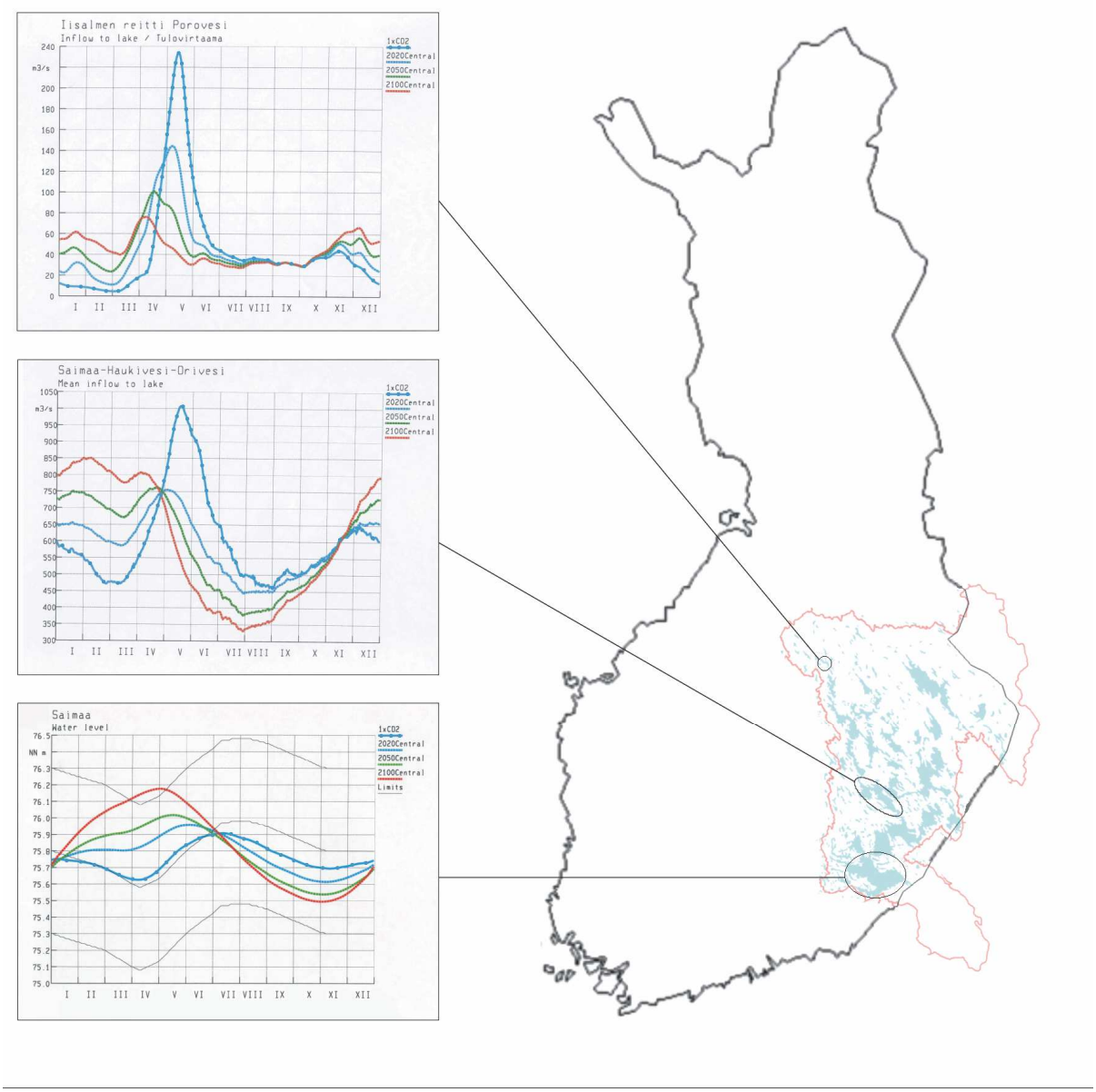

Figure 7. The change in maximum flood depends on the location of the area in the watershed. Results from the SILMU-project (Vehviläinen and Huttunen, 1997).

3. Quality of inland and coastal waters – impacts and adaptation

Lepistö, A., Niemi, J., Pitkänen, H. and Mäkinen, R.

3.1. Inland water resources, impacts and possible changes in water quality

3.1.1. Water quality monitoring programmes and current water quality

Pressures affecting the quality of inland waters originate from point sources (e.g. municipal and industrial wastewaters, fish farming), from non-point sources (agriculture, forestry, sparsely populated settlements outside sewerage systems) and from atmospheric deposition. A national physico-chemical monitoring programme of rivers was started in 1962 and that of lakes in 1965 (Niemi and Heinonen 2003). The current Finnish Eurowaternet monitoring network for rivers and lakes was established in 2000 (Niemi et al. 2001). The lake network includes about 250 monitoring sites and the river network about 200 river sites. The network will be developed further to meet the requirements set for monitoring by the Water Framework Directive (European Parliament 2000). Inland water quality at a national scale has recently been assessed on the basis of monitoring and other data sets (e.g. Mitikka and Ekholm 2003; Räike et al. 2003)

In recent decades, the quality of Finnish inland waters has improved as a result of water protection and management e.g. more efficient wastewater purification. The general water quality classification for the years 2000-2003 was recently carried out on the basis of data from 5 370 lake sites and from 3 900 river sites (Finnish Environment Institute 2005). Of the lake area, 80.2% was of excellent or good quality, 4.4.% passable and 0.3% poor. Of rivers 42.7% was excellent or good, 31% passable and 2.1% poor. Lake water quality was better than that of rivers. Although water quality has improved, the major challenges today needing increasing attention are non-point source loading and atmospheric deposition, while signs of climate change impacts are also beginning to emerge. A general presentation of Finnish inland waters was given recently by Niemi et al. (2004) and Mitikka et al. (2005) investigated the nitrate levels in Finnish waters.

3.1.2. Expected climate-induced changes in N and C losses from catchments

Many of the scenarios developed for future climate in the Nordic countries project both long-term increases in temperature and precipitation, as well as increased frequency and severity of extreme events such as floods and storms (Palmer and Räisänen 2002). Given that many of the key processes active in terrestrial ecosystems, such as the release of N and C from soil organic matter by mineralisation, are temperature and moisture dependent, climate-induced changes in N retention and losses from semi-natural ecosystems may be expected (Van Breemen et al. 1998; Wright 1998). A warmer climate can enhance both acidification and eutrophication by increasing the release of N from soil organic matter to runoff (Wright and Schindler 1995). A climate scenario for the 2050s based on the ECHAM4 model resulted in 26% more leaching of both C and N in a forested catchment at Lake Valkea-Kotinen, based on an artificial neural network (ANN) application (Holmberg 2003). In the Finnish Global Change Research Programme (FIGARE), carbon and nitrogen storages, accumulation and leaching fluxes in forest ecosystems at present and in a changed climate at different spatial scales were studied (Ilvesniemi et al. 2002). Future efforts to explore the rate and magnitude of carbon and nitrogen transforming processes in wintertime forest soils seem likely to be

well paid off by applying dynamic integrated models to boreal conditions, in co-operation between experimenters and modellers.

3.1.3. How climate change may affect inland water quality?

In low-lying, near-coastal areas of southern Finland, winters are often mild with little snow accumulation. In such regions flood peaks, together with nutrient export peaks to inland waters, occur frequently during all seasons, and usually there is no distinct spring flood. The northern parts of Finland are characterised by long (5-7 months) and cold winters with continuous snow cover, and ice cover over rivers and lakes. A snowmelt-induced spring flood in late April-May usually dominates the annual hydrological pattern, whereas less pronounced flow peaks often occur in autumn due to rainfall events. In these areas, a major fraction of the annual nutrient and carbon fluxes occurs during these high flow periods. These patterns may be changed considerably in the future, with the most pronounced change in the north, given the predictions of a warmer and wetter climate in northern Europe, see also sections 2.2 and 2.5.

The amount of dissolved materials present in inland waters depends on geology, soil, anthropogenic inputs and climate. Climate change may affect the hydrology of drainage basins and input of materials flushed to water bodies, thus affecting water quality. Extreme cases due to will potentially increase under a changed climate: during low flow events, increased concentrations of toxins, bacterial contaminants and nuisance algae are common. High flow events have been shown to increase soil erosion and chemical leaching, whereas intense rainfalls increase the risk of runoff of urban and livestock wastes and nutrients into watercourses. Projected warmer temperatures and longer growing seasons can be expected to change water quality in lakes due to increased primary production, greater organic matter decomposition and more rapidly occurring nutrient cycles in water bodies. The duration of ice cover of waters is also expected to decrease.

3.1.4. Climate change impacts on inland waters – conclusions from SILMU research

Preliminary assessment has shown that adaptation studies are few; most of the present and previous research has focused on climate change impacts. SILMU (The Finnish Research Programme on Climate Change – 1991-1995) was a multidisciplinary national research programme on climate and global change. The Water-SILMU programme was developed to improve our understanding of how the basic structure and function of Finnish water ecosystems will respond to, and interact with the complex changes in climatic conditions, land-use practices and atmospheric composition (Kauppi and Kämäri 1996), including three large projects and 13 articles in the SILMU final report.

The major findings SILMU (Roos 1996; Arvola et al.1996; Ministry of Environment 1997) were:

- Winter floods and the lack of snow cover will make the agricultural soils of southern Finland susceptible to increased leaching of nutrients.
- Nitrate leaching from forest areas may increase significantly, but the effects of enhanced forest growth can balance this increase.
- The duration of ice cover in lakes will become shorter. In some of the larger lakes of southern Finland the ice cover may even disappear in midwinter during the latter half of the century. In summer, the surface water temperatures will increase about as much as air temperatures

- The spring peak of phytoplankton will occur earlier and become clearly higher than today. The littoral zone is likely to be more sensitive to the effects of climate change than the pelagic ecosystem. A doubling of atmospheric CO_2 content and an increase of 2-3°C in water temperatures more than doubled the growth of some littoral macrophytes in an artificial greenhouse lake
- The habitats of many warm water fish species are likely to expand, especially in northern Finland. Unfortunately, most of these species have little or no commercial or recreational value. Many cold water fish will suffer from warming.

SILMU research predicted 4, 8 and 12% increases in phosphorous transport for the Gulf of Finland by 2020, 2050 and 2100, respectively. On the other hand, a 5% decrease in P transport was predicted for Lake Längelmävesi by 2100 (Bilaletdin et al. 1996). Further, Frisk and Bilaletdin (1996) predicted changes in annual dynamics: winter total P concentrations in Lake Längelmävesi would be 5 μg l^{-1} higher than the present values of ~10 μg l^{-1}, while in summer they were ~2 μg l^{-1} lower, without internal loading.

3.1.5. Modelled changes in hydrology and N cycling in a northern river basin – a case study using the INCA model

Nitrogen concentrations and fluxes in rivers are the net result of catchment N sources (non-point sources, atmospheric N deposition, direct effluent discharges, mineralisation) and sinks (plant uptake, immobilisation, denitrification). The process-oriented Integrated Nitrogen model for CAtchments (INCA) attempts to describe these factors quantitatively, by linking hydrology and N inputs from atmospheric deposition, agriculture and populated areas with the microbial processes controlling N behaviour in soils and river reaches (Whitehead et al. 1998; Wade et al. 2002). After calibration to a river catchment, the INCA model might be used as a management tool, e.g. to assess the contribution of various N sources to catchment N pools and river inorganic N concentrations. Additionally, it can be used in assessments of land-phase and in-stream responses to various scenarios of environmental change, including climate change (Wade et al. 2002).

The INCA model has previously been calibrated and tested in a river basin in northern Finland (Simojoki River) (Lepistö et al. 2004; Rankinen et al. 2002; 2004). The basin is typical for upland areas in Finland with little anthropogenic influence. Two climate change scenarios (low and high) were used based on preliminary information from the FINSKEN project (Jylhä et al. 2004), giving increases in annual temperatures by the 2050s of 1.5°C (low) and 4.0°C (high) and increases of precipitation of 4% (low) and 12% (high) over the next 50 years. These scenarios are quite close to the FINADAPT range in the mid-term 2021-2050 (Carter et al. 2005; Ruosteenoja et al. 2005).

Given the climate change scenarios, the INCA model simulated rather dramatic changes in snow accumulation and subsequently also the seasonal flow patterns at the study sites, Dalelva and Oygard in Norway and the Simojoki river basin in Finland (Figure 8) (Kaste et al. 2004). Streamwater flow patterns were predicted to be heavily affected by the reduced snow accumulation and by the fact that snowmelt might occur during the whole winter season. Additionally, the regular snowmelt flood will be less distinct and take place earlier in the spring.

N transformation rates, both within the terrestrial catchment and in the stream, are temperature dependent. The most significant change simulated by the INCA model was an

increase in N net mineralisation rates; these increased by about 20% at Simojoki (high scenario) (Kaste et al. 2004). However, the increased N availability was to a large extent balanced by internal N sinks in the soil system. No increases in NO_3^- leaching were predicted, and only a slight increase (6%) in NH_4^+ leaching at Simojoki (Kaste et al. 2004).

Uncertainties for simulating future changes in internal catchment N cycles, for different retention processes and their sensitivity to changes in soil are higher than for those concerning hydrological changes (increased melting periods, changes in annual flow patterns). Both model structures and model applications need further effort to reduce these uncertainties.

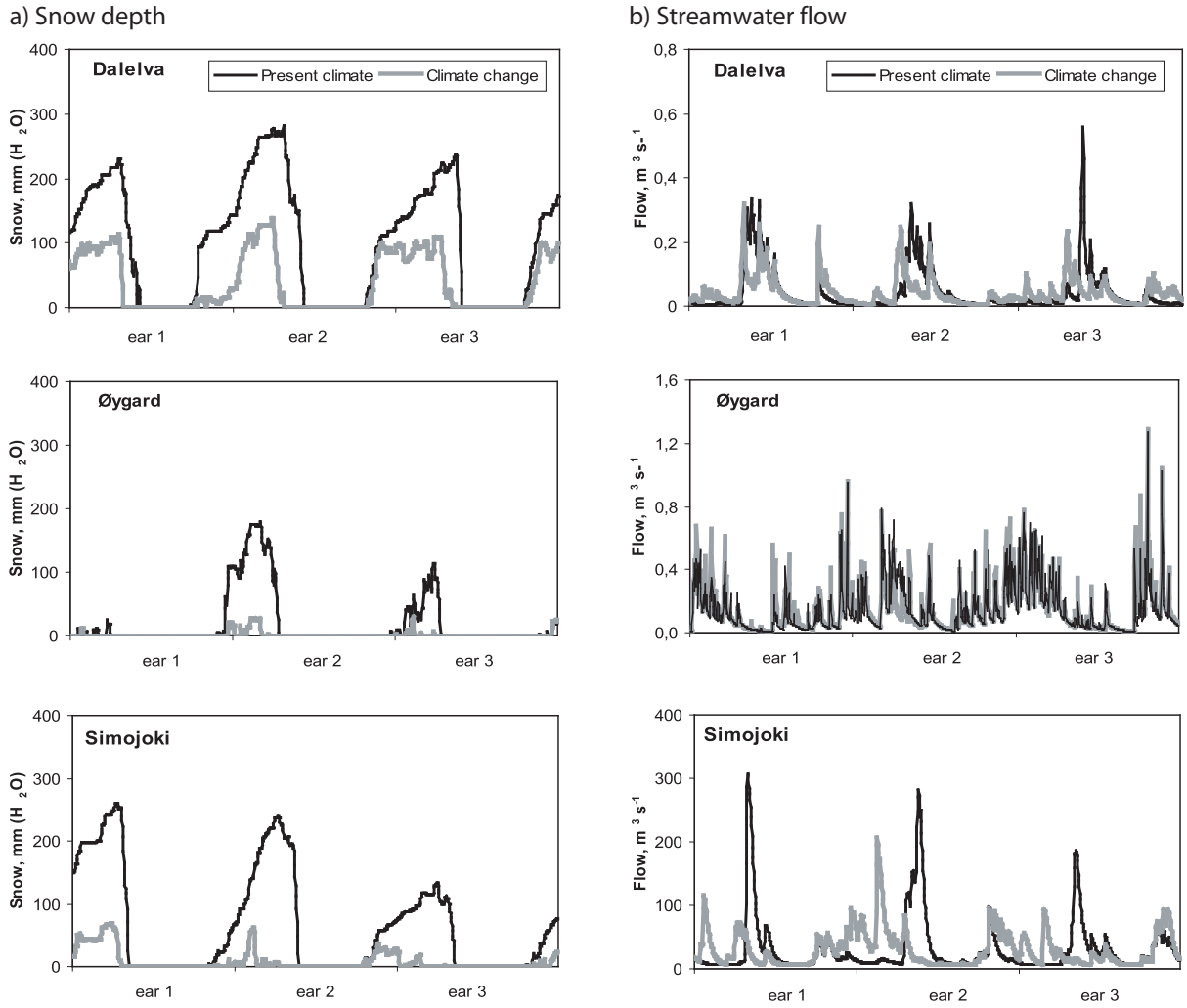

Figure 8. Predicted changes by 2050 compared to present climate in snow depth and streamwater flow under scenarios of climate change at the study sites Dalelva and Øygard in Norway and Simojoki in Finland (Kaste et al. 2004).

3.2. Groundwater

Groundwater in its natural state is usually classified as high class domestic water in Finland. The main factors causing problems with the use of groundwater are too high concentrations of dissolved iron and manganese. Finnish groundwater is in many cases soft and the pH-value is naturally low. However, due to relatively thin soil layers above the groundwater table, the risk

of groundwater contamination is considerable. The most important risks for groundwater in the short term are human activities, not climate change.

In the southern part of Finland the length of dry periods in summer are expected to increase in the future (Ruosteenoja et al. 2005). Dissolved oxygen is necessary for good water quality. Groundwater discharges slowly, resulting in a shortage of dissolved oxygen. That causes more problems with high concentrations of dissolved iron, manganese and metals. Other harmful factors may be ammonium, organic matter, and gases such as methane and hydrogen sulfide, which adversely affect the taste and odour of groundwater. The amount of dissolved materials present in groundwater depend on the geological conditions of the soil formations. In wintertime, increasing precipitation will produce fresh and oxygenous groundwater. In the northern part of Finland climate change should even out the seasonal movement of groundwater and hence its quality. Groundwater, although filtered by natural processes, is often susceptible to microbial contamination. Thin soil layers above the groundwater table add the risk of groundwater contamination by bacteria. That can happen especially when the surface water is flooding or rainwater runs straight into rural wells.

The hydrological processes concerning groundwater in Finland are not sufficiently well known. Research into hydrological, chemical, biological and geological processes in soil, in the unsaturated zone and the groundwater zone should first be increased, in order to make predictions for the future.

3.3. The Baltic Sea and coastal zone

Eutrophication is regarded as the most severe problem of the Baltic Sea and its coastal waters. Some basic reasons for this are the high loading of eutrophying nutrients, phosphorus and nitrogen, related to natural conditions of this enclosed sea, shallowness, vertical stratification and long residence time. The main source of external nutrients is non-point loading from agriculture. In addition, considerable amounts of nutrients originate from municipal sources. Atmospheric wet deposition originating from traffic, industry and agriculture is an important source of nitrogen, comprising about 25% of the total nitrogen input (1 million ton/yr) to the Baltic Sea.

Considerable parts of the Finnish coastal waters are eutrophied compared with corresponding open sea areas. This is a result of land-based nutrient loading together with the shallowness and very complex topography of the coastline, which weakens the horizontal exchange of water.

The potential effects of climate change to the Baltic Sea are either direct (affecting e.g. stratification, currents, biological productivity) or indirect due to changes in the catchment. Projected future increases in nutrient leaching can be expected to cause eutrophication in coastal waters. The Finnish coastal water areas most evidently affected by this extra load would be those off the southern and south-western coasts, due to the intensive cultivation of these coastal areas and the almost total lack of lake retention in the river catchments.

According to the results of the SILMU project (Kuusisto et al. 1996), under a scenario of annual warming (by about +0.4°C per decade) and precipitation increase (by about +1% per decade), non-point loading of total phosphorus and total nitrogen into the Gulf of Finland were estimated to increase by 8% and 6%, respectively, by the year 2050 and 12% and 11%, respectively, by the year 2090. Most of the increase would take place in the winter/spring

months (December-April). As a result, the vernal production of phytoplankton would increase because the increased nitrogen load would reach coastal waters before the nitrogen limited vernal bloom.

Increased vernal phytoplankton production would increase the sedimentation of oxygen consuming matter. This increases the risk of anoxic conditions and internal loading at the sediment-water interface, with adverse effects on the living conditions of benthic fauna. Increased internal loading would further accelerate eutrophication.

3.4. Potential impacts, adaptation and R&D needs under future climate change

In the following, six likely future impacts of climate change (**Impacts 1 to 6**) are listed, together with possible adaptation needs and research requirements:

3.4.1. Impact 1: Increase of erosion, organic carbon and nitrogen leaching from forests during high flow

Adaptation:

- Adaptation requires changes in land use. The forest management practices increasing erosion should therefore be kept under control e.g. by better planning of supplementary forest drainage works, by introducing lighter forest soil treatment methods, and by avoiding cutting works if there is not enough frost in forest soil.
- Water pollution control targets must be clarified with more emphasis on organic fractions of nutrients

R&D needs:

- Further development of forest management practices to prevent erosion and nutrient leaching
- To assess combined impacts of changes in climate and land use in forested catchments by using integrated catchment models

3.4.2. Impact 2: Algae blooms become more frequent (restrictions to recreational use of waters, increased risk of blue-green algae toxins)

Adaptation:

- Present weekly national algal surveillance used for reporting algal nuisances to the public has to cover more water bodies. More frequent reporting to the public necessary?
- Bathing restrictions for beaches
- Beaches with frequent algae blooms have to be closed totally and new ones to be opened, in some areas swimming-pools have to be constructed
- Removal of macrophytes and macroalgae from beaches – required costs?
- Effects on fish populations? Restrictions to eat fish because of algae toxins and increase of fish import

R&D needs:

- How to adapt to increased frequencies of algal blooms – concerning lake ecosystems and recreation

3.4.3. Impact 3: Flooding increases; both winter floods due to melting and summer floods due to high intensity rainfall

Adaptation:

- Improved planning for preparedness for severe floods

- Evaluation of drainage systems (agriculture/forestry)
- Floods increase turbidity in waters which affects fish species and fishing. New fishing grounds may have to be sought. Fish species farmed presently may have to be replaced by other species
- Water conservation measures

R&D needs:

- Studies that focus on understanding and defining critical thresholds (critical floods) in water resource systems

3.4.4. Impact 4: Ice covered season becomes shorter/less snow in the south

Adaptation:

- Moving on ice becomes risky. More information to the public needed.
- Evaluation of water quality monitoring programme during winter period
- In some water bodies oxygen content will be higher, which improves water quality and helps the measures in water quality management.
- In lakes rich in organic matter increased temperatures may accelerate decomposition processes and result to oxygen deficit and eutrophication. Fish kills may become more common. Lake restoration works become necessary.

3.4.5. Impact 5: Longer drought periods

Adaptation:

- Changes in lake/river ecosystems and groundwater aquifers with concentrated nutrient loads in smaller water volumes; water conservation measures needed
- Improved planning for preparedness for severe, long drought periods
- Improved surface- and groundwater quality protection from non-point source pollution

3.4.6. Impact 6: Increasing N/P loading to inland and coastal waters

Adaptation:

- The use of nitrogen/phosphorus fertilizes in agriculture may have to be reduced to counteract increased leaching losses due climate change. More effective prevention measures needed.
- Due to increased N leaching, the P limitation of lakes will be more pronounced and more excess N will be transported via watercourses to mostly N limited coastal waters, management needs
- Changes in cultivation practices in agriculture, e.g. prevention of erosion and increased cultivation of winter cereals
- More effective prevention measures in reducing nutrient input from river basins necessary
- Eutrophication increases, particularly in littoral zones- this limits the recreational use of some waters
- An important precautionary measure is to reduce the present nutrient loading to coastal waters; to cut loads from national point and non-point sources and from St. Petersburg in Russia

R&D needs:

- Integrative studies which look at the ecological controls and human influence on the vulnerability of water to climate change, and corresponding increasing demands for lake management

- Impacts of increased riverine nutrient fluxes to estuaries and coastal waters –utilization of increased amounts of organic C and N by microbes/algae and channeling of nutrient and energy fluxes in coastal ecosystems
- Better integration of river basin modelling (hydrology and nutrients) with coastal modelling, with weather radar data, with remote sensing based information, and with high frequency measurements of water quality
- Cost-effectiveness in reducing nutrient loads to the Gulf of Finland

4. Water resource and coastal management – impacts and adaptation

4.1. Water supply and waste water systems

Arosilta, A.

4.1.1. Present climate-related problems are expected to become more frequent

Current climate conditions occasionally disturb water supply, sewerage and wastewater treatment. The severe drought in 2002–2003 caused shortages in urban and rural water supply. Heavy rains in the summer of 2004 caused hygiene problems in water supply and increased discharges exceeded the capacities of sewer systems and wastewater treatment plants. Small water utilities and wastewater systems with combined sewers were found to be most vulnerable to these problems. A changing climate is not likely to introduce new threats for water supply and wastewater systems, but the present climate-related problems can be expected to become more frequent. The main measures to tackle these problems are increased co-operation between water utilities, alternative reserve systems, expansion of networks to rural areas, enhancements in water purification processes (e.g. disinfection), replacing combined sewers with separate sewers and repairing network leaks.

4.1.2. Impacts and adaptation measures

Flooding and heavy rains cause problems for both water supply and sewerage. Rising river or lake levels and massive surface runoff can enter wells and even flood them. Wells located on river banks or lakesides are especially vulnerable. The washout can contaminate the water of improperly constructed or maintained wells. Increased precipitation may also accelerate the formation of groundwater and thus decrease the purification capacity of the ground. Increased runoff will increase contaminant washout to water bodies, and therefore surface water treatment processes may also require enhancements. The heavy rains in summer 2004 flooded and contaminated several groundwater wells. The problems were most common in small groundwater utilities. These utilities seldom have any disinfection system and thus are vulnerable to sudden contamination. Continuous use of disinfection or even a temporary disinfection system in reserve would diminish hygiene problems associated with floods and heavy rains, but also hygiene problems due to drought and other emergencies. During the heavy rains in summer 2004 private wells were also flooded and contaminated. It is common that private wells are in poor condition and thus easily contaminated by surface runoff. Private well owners need to be educated about the importance of well maintenance.

Strongly increasing maximum precipitation will increase urban flooding. More frequent exceedance of the capacity of storm water pipes and combined sewers can be expected with this increased runoff. Urban floods are discussed in more detail in section 4.2. Snowmelt floods currently cause problems each year for some wastewater treatment plants due to leaks and multiplied discharge rates. A decrease in spring runoff may decrease the current discharge problems of the wastewater treatment utilities. The heavy rains in the summer 2004 exceeded the capacity of sewers in southern Finland, and some untreated sewage was received into water supplies over a period of several days. The amount of municipal wastewater is not expected to increase, but the storm water discharges would be, because of the projected increase in precipitation. Therefore, there is no point in increasing the capacity of wastewater treatment plants. On the contrary, the capacity modifications should be directed towards storm water piping, separate drainage and treatment of storm water. The drainage of storm waters

should increasingly be piped into separate sewers. Repairing of network leaks is also crucial for separate sewers in order to decrease the multiplied discharge rates during maximum precipitation.

A future rise in temperature will result in the more frequent occurrence of algal blooms. In water bodies rich in organic matter it may also cause oxygen deficit. These consequences cause problems for surface water intakes. Both algal toxins and increased amounts of dissolved phosphorus, sulphates, iron etc. resulting in decreased oxygen content in raw water require treatment process modifications or enhancements for surface water utilities. For example, temporary or permanent use of activated carbon filters may be needed to remove blue green algal toxins from raw water. Warming can also cause oxygen deficit in groundwater. Dissolved iron, manganese and sulphates, in particular, may require enhancements in the generally simple purification process of groundwater. Warmer summers may give rise to increased irrigation demand (see section 4.6.4). Finnish surface waters are mostly usable as such, without treatment, for secondary needs such as irrigation, car washing, etc. Dual water systems may be promoted where considered practical.

Although the impacts of climate change are generally negative, there may also be some positive ones. In a long time-frame a significant rise of temperature may benefit the wastewater treatment due to increased microbial activity. In Finland the removal of nitrogen is limited by the cold climate. A shorter winter may improve the preconditions for the removal of nutrients.

The general availability of groundwater may improve due to increased precipitation and shorter wintertime. However, present problems associated with water shortage mainly occur during extreme conditions, i.e. long dry periods. Dry summers and droughts are likely to be more frequent, and small groundwater basins will be the most prone to drying. This will hinder small groundwater utilities and private well owners, in particular. During the drought period in 2002-2003, some water utilities had problems with the quantity and some even with the quality of raw water. However, the drought had the most severe impacts on the rural water supply: water had to be delivered to thousands of dried up wells by tankers (Silander and Järvinen 2004). Most well-owners as well as many authorities were not prepared for the impacts. The increasing risk of dry summers resulting in lower water levels may increase the negative impact of discharged wastewater in the receiving body of water. Even well treated wastewater may cause a considerable load especially in small recipient water bodies with a decreased volume.

4.1.3. Preparedness of the Finnish water supply and wastewater sector

A working group appointed by the Ministry of Agriculture and Forestry has published its final report on the preparedness of the Finnish water supply and wastewater sector for unusual events and crises (Maa- ja metsätalousministeriö 2005). The adaptation measures presented here are mostly based on the recommendations of the working group. The predicted impacts of climate change are already familiar to the Finnish water sector. However, some extreme events are projected to become more frequent under a changing climate. It is recommended that the water supply and wastewater utilities prepare themselves for unusual events. Adequate and diverse preparedness for current risks will most likely be sufficient, at least for the temporary impacts of climate change (floods, drought etc.). However, adaptation for permanent changes probably requires specific, and new, measures.

Reserve systems and co-operation between water utilities is essential during periods of water shortage and quality problems as well as during other emergencies. At present, half of the water utilities are estimated to have connections to a network of another utility. About one-fifth of the water utilities have alternative water intakes.

Improving the utilization of the nationwide information systems, e.g. groundwater level surveillance and surface water quality surveillance, is essential for water utilities. Groundwater and water services information systems (POVET, PIVET, VELVET, VAHTI) are currently in operation and will enhance the ability to define problem areas.

Possible adaptation measures under the impacts of a changing climate and some priority needs for research and development are summarised in Table 2.

Table 2. Impacts and adaptation measures due to climate change for the water supply and wastewater sector.

Area	Impact	Adaptation measure	Research needs
Water supply	More frequent droughts: water quantity and quality problems especially for small groundwater utilities and private wells.	Ensured water supply, e.g. connected networks or alternative water intakes. * Increased ground water level monitoring by water utilities. * Increasing the coverage of water supply networks. */**	Development of real time observation and forecasting systems of groundwater levels available for groundwater utilities. * Short- and long-term changes in groundwater quality due to drought. *
	Increased runoff and washout to raw water reservoirs	Enhancing surface water treatment processes. **	
	Increased risk of flooding: contamination of wells.	Disinfection systems for small groundwater utilities; more frequent quality control during rains.* Instructing private well owners on well maintenance. *	The impact of increased precipitation on the purification capacity of the ground. *
	Rise of temperature resulting in more frequent algal blooms in surface water and increased levels of dissolved phosphorus, sulphates, iron etc. in surface and groundwater.	Control of raw water reserves during the risk period. * Temporary or permanent treatment process modifications. */**	
Wastewater treatment and storm water management	Increase of heavy rain induced urban floods: exceeding capacities of storm water pipes, combined sewers and treatment plants with combined sewer systems.	Repairing of network leaks.* Increasingly piping storm waters into separate sewers. **	Revision of hydraulic design criteria for storm drain systems. *

* 0-10 years, ** 10-50 years, *** > 50 years

4.2. Flood risk management

Silander, J., Ollila, M. and Vehviläinen, B.

4.2.1. Floods and flood risk in Finland

One of the most frequent environmental hazards in Finland is flooding. Various types and magnitudes of floods are characteristic of Finnish conditions. Typically floods are caused by

thawing of snow, high rainfall, wave extremes and ice jams, but very seldom by dam failures. Average annual flood damage was over one million euros between 1974-1998. In 1988, a major spring flood alone caused around 4-5 million euro damage. In 1899, an exceptional flood, which occurs every 500-1000 years, caused the equivalent of nearly 30 million euro of damage as flood water covered over 1400 km^2 (Ollila et al. 2000).

In northern Finland snow melt induced *spring floods* will likely be more common. Examples of severe snow melt floods were experienced in the cities of Kittilä and Ivalo in spring 2005. At the end of May 2005 around 20 people were evacuated from Ivalo and in early June, 2005 over 100 people from Kittilä.

In southern Finland *summer floods* may become common, especially, when the percentage cover of lakes is small. An example of the adverse impact of heavy rainfall-induced summer floods was observed in August 2004, when severe heavy rainfall induced floods occurred in western, central and southern Finland. Precipitation during August varied considerably and a 24 h precipitation figure of 151 mm was recorded at Oravainen in southern Ostrobothnia on 3 August 2004. The flood damaged some roads and buildings. Elsewhere, areal precipitation in the Vantaanjoki river basin between 27 July and 2 August 2004 was about 120–170 mm (Figure 9). Total damage was estimated to be over 5 million euros.



Figure 9. Near the Vantaanjoki in river basin, August 2004 (Photo: Kari Syrjälä).

Wave extremes associated with a temporary sea level rise due to *storm surges*, can cause damage in coastal areas of Finland. As an example, strong winds in January 2005 raised sea level on the southern coast by around 80 cm in eight hours. In Helsinki, the average water level rose to around 1,5 metres above the average sea level, setting a new record for the period back to 1904 when observations began. In Hamina, the rise was nearly 2 metres. Hundreds of vehicles were flooded in harbour areas and the total damage was estimated to be between 15 and 20 million euro (Turun Sanomat 2005). The sea level rise typically occurs due to a combination of air pressure fluctuations, wind and water flow through the straits between Denmark and Sweden.



Figure 10. The market square in downtown Helsinki flooded due to a high sea level on 5 January 2005 (Photo: Mikko Sane).

In the Extreme Flood Project, the Regional Environment Centres made flood damage estimates for almost 400 risk areas. According to these estimates, the sum of damage costs of extreme floods occurring in all risk areas of the country would be around 550 million euros. However, the probability of such extremes occurring everywhere in the country during a single year is extremely unlikely. Divided according to various human activities, 52% of the damage could be expected to be caused to buildings, 20% to industry, 17% to agriculture, 6% to roads and bridges, 3% to forestry and 2% to public service (Figure 11). It is interesting to note that in 1899 damage to buildings was 2%, industry 35% and agriculture 56% (Ollila et al. 2000).

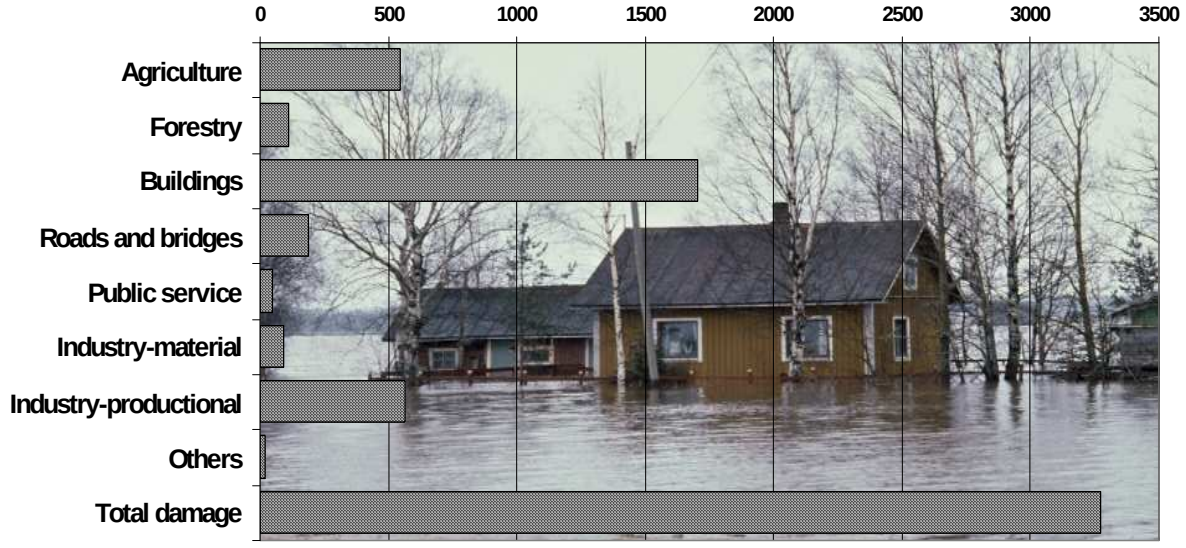

Figure 11. Flood damages according to the Extreme Flood Report (Ollila et al. 2000), using the 1999 price level (x-axis in millions of FIM, one euro is 6 FIM).

4.2.2. Adaptation to the future climate change for flooding events

Winter and spring floods

To take care of the excess water it is possible to change the regulation of lakes, build up new retention basins, reduce the number of drainage ditches, increase free storage capacity and increase outflow capacity of dams, e.g. building bigger spillways. More capacity for flood waters should be left in regulated lakes and reservoirs, especially for heavy precipitation in wintertime.

The formation of frazil ice will possibly increase, and therefore its impact should be further studied. The frequency and severity of frazil ice and ice jams may also necessitate some alterations in the water course regulation and hydropower discharging permits, to minimise potential problems.

An exceptionally sensitive area, not only with regard to spring floods but also to sea level rise, is the town of Pori, where around 20 kilometers of dikes wil probably need to be raised in order to maintain the same safety level as today. This construction, for Pori alone, could cost between one and ten million euro.

Summer floods

The same methods that are used to mitigate spring floods could also be used to mitigate summer floods in riverfront areas such as in the town of Kittilä.

Heavy rainfall incidents are likely to give rise to increased water quantity and quality problems in the municipalities. In urban areas, the overloading of storm water systems may cause basement flooding, sewage water may end up to the drinking water causing water-borne diseases, and rivers may become polluted. Adaptation requires better design of water related structures. Wastewater pumping stations and water supply systems may have to be redesigned to diminish these problems.

In urban areas, storm water drainage systems may need improvement or new innovative uses of technology may be required. Designs can be improved by updating the design guidelines that account for precipitation intensities. The capacity of storm water systems can be increased and temporary storages for water may need to be built, or other methods used to improve the water retention capacity in urban areas. Both an excess of water and increased summer irrigation demand must be taken into consideration in land use planning. Increased runoff on paved areas will require better storm water management. Since the majority of urban drainage systems are designed on the basis of historical climate records and the urban area is expanding continuously, it is probable that these systems will fail more frequently under a changing climate.

Research is also needed to manage groundwater resources, especially in urban areas. To reduce vulnerability to climate change we should concentrate on the most vulnerable urban areas. More reliable forecasts of rainfall events and warning systems should be developed. Information and guidance should be given to private households and building owners on the means to prevent and mitigate damage caused by heavy rainfall-induced floods. Common good practice adaptation measures should be compared with neighbouring countries.

Wind storm induced floods and sea level rise on the seashore

Along the coast there are several harbour and storage areas that could have been protected in the flood of January 2005 by using temporary movable flood protection structures. This kind of equipment should be collected in some depots. Moreover, dikes may need to be built to protect some housing areas especially on the seashore. Additionally, in the long run, adaptation requires changes in land use planning along the coastal areas.

Obviously, storm surges combined with sea level rise will cause coastal squeeze in some areas, increasing the economic risk of flooding. Adaptation to climate change may require strong permanent and temporal defenses to prevent such flooding and re-establishment of natural floodplains. In the most threatened areas on the seashore, kilometers of levees may be needed and pumping devices should be reserved for protection. Also some coastal roads and bridges may need to be improved as well as sewage and drainage water outlets. It is clear that public participation is necessary in the cities near the coast, where the economic risk of flooding will increase along with a rising sea level. New decisions of lowest acceptable building levels have already been introduced. Other additional restrictions may need to follow.

Summary: flood risk

All of the above measures require public participation, otherwise socio-economic barriers can arise for adaptation, resulting in conflicts between municipalities and land owners. The most important recommendations in adaptation to climate change are listed below and presented in Table 3.

- Watercourses should be considered as entities in order to find the best means for flood mitigation, such as alteration of watercourse regulation and use of water retention areas.
- Administrators should regularly estimate and if necessary update recommended building elevation levels and design precipitation values, prepare flood maps from sensitive areas and flood mitigation plans.
- Real time water level observations and flood forecasts should be made available for the public to improve preparedness against flash floods.
- Preparedness for extreme floods should be increased e.g. by developing simulation software for flood exercises.
- Flood awareness should be increased by making e.g. real time flood maps available on the Internet and the lowest building levels and design values easily accessible for the public.
- Some changes in regulations are needed in urban areas, e.g. area impermeable to water should be manageable.
- Municipalities along coastal zones should map and manage flood risk, e.g. they should decide if an area is suitable for construction and how long and with what measures; probably some new town plan guidelines are also needed.
- The flood control systems should be maintained and developed so that they can cope with extreme floods.
- The risk of storm surge flooding and sea level rise should be taken into account, in more detail, in land use planning and flood mitigation.

Table 3. Impact and adaptation measures for flood control.

Impact	Need for adaptation action	Research and development needs
Spring floods are increasing.	Build up new retention basins.**P Increase outflow capacity, e.g. by building bigger spillways and using them especially during winters. **P	Improve land use planning.* Update heavy rainfall design guidelines for urban areas.* Develop flood portal.* Estimate formation of frazil ice in near future.**
Summer floods are increasing	Shorter observation and forecast periods are needed, especially in flash flood situations, to improve flood preparedness.*P	Consider giving flood warnings in urban areas.*P Lake regulation patterns should be developed more adaptive for flooding during wintertime as well.*
Heavy rain induced urban floods are increasing.	Detention areas should be considered in urban planning. In land use planning the impervious area should be managed, e.g. to allow water to infiltrate to the groundwater.*P Increase retention volume.**P	New town plan guidelines should be introduced.*P Disconnect impervious areas from the storm water drainage system e.g. disconnect roof and drain water on the lawn. ** Build underground containers.***
Wind storm induced floods and sea level rise on the seashore.	In some areas movable flood protection structures and equipment should be collected in depots.*P Construction of dikes may be necessary.***	

Adaptation: A anticipatory, S autonomous, P planned, R reactive.
* within 0-10 years, ** within 10-50 years, *** over 50 years

4.3. Water course regulation

Dubrovin, T., Keskisarja, V. and Silander, J.

There are approximately 220 regulation projects in Finland, which affect more than 300 lakes or reservoirs. A regulation project has one or more objectives, typically flood control, hydropower production, water supply, recreation, water protection or navigation. Each regulation project has a legal permit, which defines the water level and discharge limits that must be taken into account. Regulation permits are licensed by the environmental permit authorities.

Predicted changes in water resources (section 2), particularly an increase in the total amount of water, reduced or earlier spring flooding and less predictable floods, will cause pressures on regulation practices. In a typical hydropower and flood protection-oriented regulation, the water level is raised in autumn in order to gain larger hydropower production during winter and lowered before the spring flood to avoid flood damage. In a changed climate, the winter draw-down needs to be undertaken earlier, reduced or even removed so that drought is prevented and the summer water level is feasible for navigation and the recreational use of the watercourse. Due to larger projected runoff in winter, undertaking the winter draw-down also means larger release, which can cause flooding downstream. Because of less predictable floods and more severe extremes, more attention will be required on reservoir operation and additional buffer capacity may be needed in regulation. Due to these pressures, there is increased need to revise many regulation permits. Part of the revisions can presumably be done within the limits of current regulation permits. Furthermore, according to Finland's water legislation, regulation permit conditions can be revised if earlier conditions cause remarkable damage to the water environment and its use. The costs and workload involved in revising an existing regulation permit or applying a new one depends largely on the magnitude of the project and whether the project needs to be processed by a public proclamation or a larger

inspection. However, recent experiences, such as ongoing revision of the regulation of Lake Päijänne, have shown that revision of regulation permits and even the lighter public proclamation process can be laborious, taking 3-5 years, or more.

Earlier spring and decreasing winter snow water equivalent will affect most of the regulations. Figure 12 shows an example of a lake regulation where the upper limit (black line) of an old regulation permit is already frequently overtopped. Similar problems are expected in many areas.

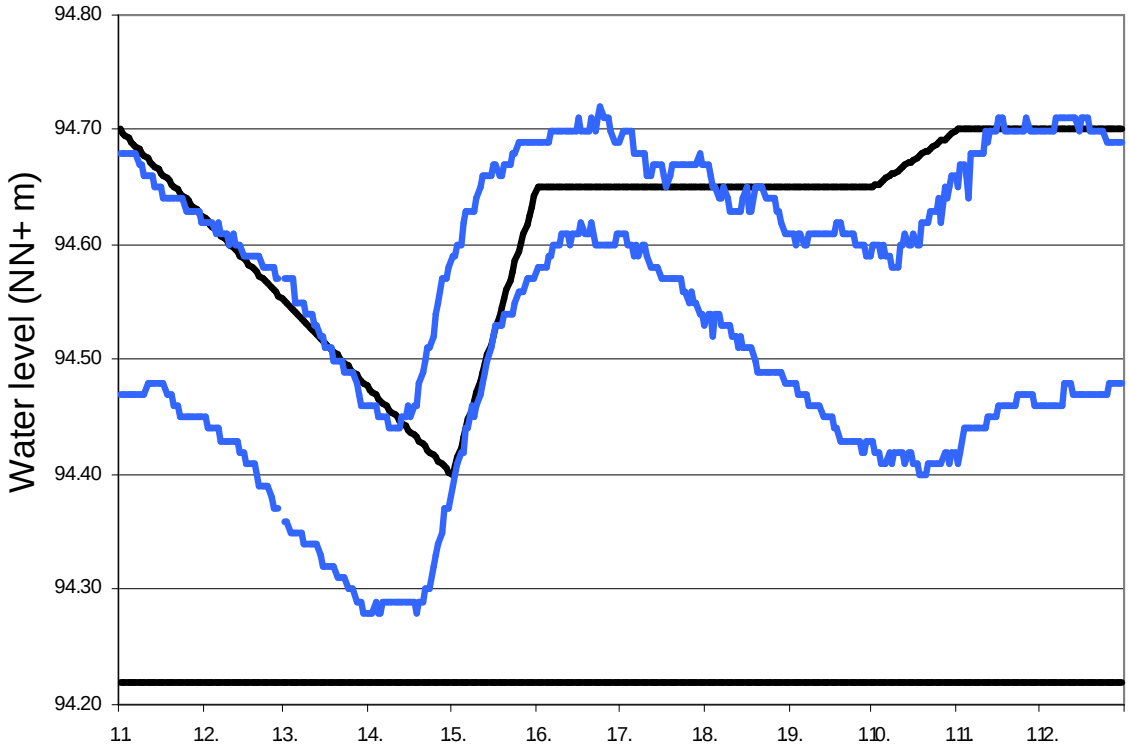

Figure 12 Lake Puula, regulation limits (black) and yearly water level variation (blue, 25% and 75% fractiles, 1964-2003, in x-axis time).

Simple spatial analysis based on calculated and forecasted areal snow water equivalent distributions shows that 65 percent of regulation projects are in the region where winter snow water equivalent is more than 100 mm. However, by 2071-2100 this is estimated to fall to only 26%. On the other hand, only 5 percent of regulation projects concern central lakes of large catchments, which are forecasted to have more frequent winter floods. Risk of damage will also increase in fast flowing river systems of the coastal area, where 35-40 percent of regulation projects are located. Based on the above analysis, it can be roughly estimated that more than half of the regulation projects will need revisions, but to comprehensively estimate the changes needed in regulation practices as an adaptation to climate change, watercourse regulations should be considered individually. For example, the magnitude of foreseen problems and feasible technical limits of an individual regulation project will obviously have a significant role in determining the most appropriate adaptation measures. There are recent examples of regulation development projects, but climate change and adaptation should be more comprehensively investigated in such projects, or the issue itself could be a motivator for new development projects. Before presenting new recommendations for regulation, it is important that their appropriateness in changing hydrological conditions is properly analyzed.

Lake Pielinen is an example of several non-regulated lakes in Finland, where regulation is technically possible, but there is currently no regulation permit and the release equals the natural discharge. For such lakes, as well as for those lakes where a permanent regulation permit already exists, a regional environmental permit authority can issue a temporary exceptional permit to deviate the regular release in order to mitigate flood or drought hazard. Since 1980, an exceptional permit has been issued eight times for Lake Pielinen. This is not an alarming frequency, but if the risk of extreme water conditions increases, a more flexible procedure for flood and drought prevention will be needed. Therefore, it may even be necessary to establish new regulation projects in the more distant future.

Flood awareness should be increasingly considered in land use planning, particularly in flood mapping and specifying the lowest building levels. In a changed climate, flood mitigation requires a shorter reaction time in reservoir operation, which can be achieved through more reliable, frequent and rapidly delivered observations and qualified inflow forecasts. Faster decision-making requires regular education of the operators, sound information and decision support systems and a quality assurance plan. Additionally, more extreme inflows may postulate the regulation permits to allow larger peak releases. This may also require structural changes to enlarge the outlets. Flood preparedness will not be necessarily focused in the spring period alone, but rather all year round.

In general, hydropower production is expected to increase due to increased discharges. However, the regulation practices may have to be adapted to increased winter floods and peak releases as mentioned above, which can be a disadvantage to hydropower production.

In general, diminishing the winter draw-down in regulation practice benefits the ecology. However, case-specific investigation is needed to confirm the benefit. In some specific cases, if the ecology is highly valued and is the primary concern, measurements may have to be carried out at the expense of other interests such as hydropower. Maintaining the water level at an appropriate level for recreational use in summer becomes more difficult if the differences between years and unpredictability increase. On the other hand, the lowest spring water levels rise if the winter draw-down is moderated, and this diminishes the adverse impacts on recreational use.

Table 4. Impacts and adaptation measures due to climate change in water course regulation.

Impact	Adaptation measure	Research needs
Exceeding water level limits due to reduced spring floods and higher floods in other seasons.	Revision of regulation permits, e.g. reduced winter draw-down. ** Establishing new regulation projects **	Evaluation of current regulation permits and regulation practices against climate change.* Incorporation of climate change considerations into the regulation development projects.* Simulation of regulation in Pielinen to estimate how long exceptional permit is good and when a regulation permit might be needed.**
Increase in variability and total volume of runoff.	Better operative use of regulated reservoirs e.g. more accurate and frequent observations and forecasts.** Reconstruction of outlets.**	Development of decision support systems and forecast models.*
Impacts of changed water level and flow regime on economy, society and ecology.	Integration of multi-objective analysis into the planning of new regulation policies.**	Assessment of economic, social and ecological effects of watercourse regulation in changing hydrological conditions.*

* within 0-10 years, ** within 10-50 years, *** over 50 years

4.4. Hydropower production

Suomalainen, M. and Veijalainen, N.

4.4.1. Climate change and hydropower production

Climate change influences hydropower production through changes in temperature, precipitation and evaporation. About 20% of electricity in Finland is produced by hydropower. Possible future changes in hydrological systems in Finland are therefore important for the nation's electricity production. In the near-term period by 2030s the total runoff and hydropower production increases slightly (0-10%) and the yearly distribution of water becomes more favorable to water power production. By 2100 the total runoff is estimated to increase by 0-60% depending on the scenario. For the main hydropower production watersheds in Finland, the changes in total runoff by 2080s estimated with two climate scenarios were –1 - + 40% and the largest increases were in northern Finland. Increased runoff naturally has the potential to increase hydropower production, if the inflows can be utilized.

The overall effect of the climate change can cause winter discharges to increase and the spring floods to decrease. This means less spillage during spring at hydropower plants. The drawback is that also the extreme conditions, droughts and floods caused by extensive rainfall will become more common. In watersheds with large central lakes, winter floods may increase and spillage may increase during autumn and winter. In the future, longer summers with higher total evaporation over the summer period may cause some water shortage and decrease hydropower production. The uncertainty of the wetness of the future summers and the increase in the variation of winter inflows in northern Finland will complicate the planning of the use of the water resources.

4.4.2. Adaptation measures for hydropower

Adaptation to climate change for hydropower will include changes in the planning and operation practices of power plants, changes in the regulation of reservoirs and at some sites possible increases in hydropower production capacity to enable the full utilization of the increased discharges.

Research needs for hydropower include research on the distribution and magnitude of discharge in the future on important sites to identify the sites where increasing hydropower capacity will be beneficial. The research needs associated with dam safety and regulation are also closely connected with hydropower production.

4.5. Dam safety

Veijalainen, N. and Vehviläinen, B.

Climate change will affect dam safety because magnitude and timing of floods will change and heavier rains and stronger winds projected by climate scenarios will cause floods to rise faster and will cause more structural strains and erosion on the dams.

4.5.1. Effects of climate change on design floods of large dams

In Finland high-risk dams, P-dams, are designed to withstand floods with return period of 5 000-10 000 years. Climate change will affect the design floods of P-dams and also the structural stresses of the dams. Extreme floods may increase more than average floods,

because extreme rainfalls have been estimated to increase more than monthly or seasonal precipitation.

Effects of climate change on design floods have been evaluated at the Hydrological Services Unit of Finnish Environment Institute. The time period considered is 2070-2100 and calculations are made with five different climate scenarios, which are similar but not exactly the same as the official Finadapt scenarios. In the simulations with hydrological model, design precipitation (Solantie and Uusitalo, 2000) with two weeks' length and a return period of 1 000 years is moved through 40 years of weather data (1961-2000) day by day. The flood causing the highest outflow demand at the dam is the design flood. The calculations are then repeated in conditions of 2070-2100 with regulation schedules modified if necessary. To get the full range of possible changes, daily precipitation and temperature are changed with delta-change method according to five climate scenarios and the design precipitation is changed separately according to two scenarios estimated from Tuomenvirta et al. (2000). The increase in design precipitation is between 12-40% in the smaller case and between 35-50% and even up to 85% for small watersheds in the larger case (Figure 13).

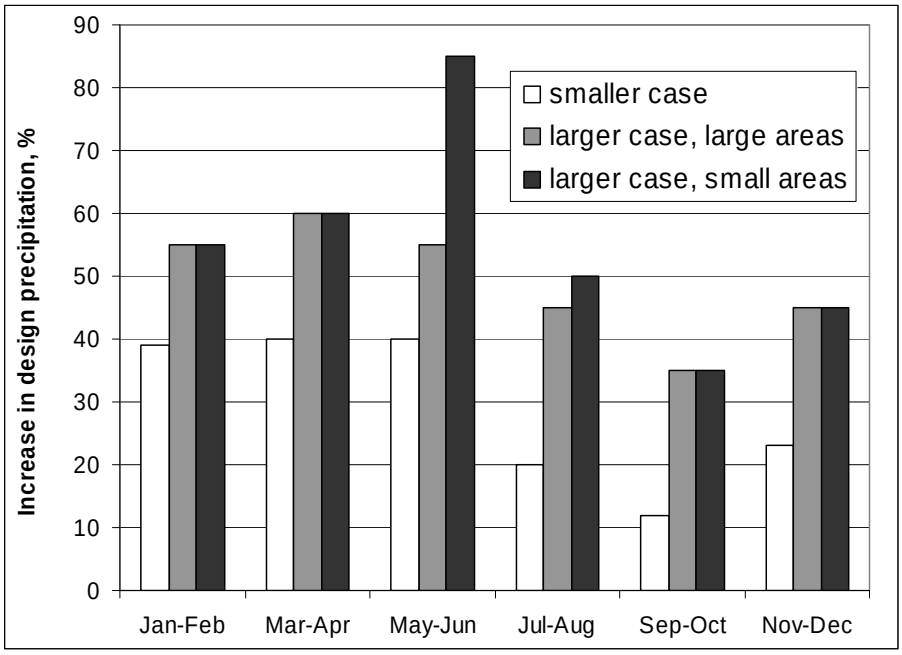

Figure 13. Increases in design precipitation by 2070-2100, smaller case and larger case (Tuomenvirta et al. 2000).

In northern Finland, the timing of the design floods remains at spring during 2070-2100 and the design floods are still caused by combination of snowmelt and rainfall. The magnitudes of the design floods stay about the same and the floods are very sensitivity to changes in temperature. Even though the temperature increases and the amount of snow decreases, the increases in winter precipitation and the design precipitation compensate this change so that the design floods increase with some climate scenarios and decrease with others (Figure 14). This is the projected change in the long term, but on a shorter time scale, 2010-2050, the spring floods will probably increase since the winter precipitation is projected to increase but the temperature increase is not yet sufficient to considerable shorten the snow covered period.

In southern and central Finland the future design floods will be caused by heavy rainfall during summer or autumn. These design floods will increase; at some dams the increases can be considerable, although the range of possible changes is quite large (Figure 14). In eastern Finland, where the design floods change from spring floods at present to summer or autumn floods in the future, the change in design floods depends on the climate scenario.

The main cause of the increased design floods is the projected increase in design precipitation. Partly the increases in design floods are due to the limited regulation capacity of the reservoirs at summer and autumn; regulation decreases the spring floods effectively because the reservoirs can be emptied for snowmelt flood, but at summer and autumn the lakes and reservoirs are most probably quite full and the possibilities to decrease the floods with regulation are smaller. The largest increases in design floods occur on dams with small runoff areas and small storage capacity and these floods are most sensitive to changes in design precipitation.

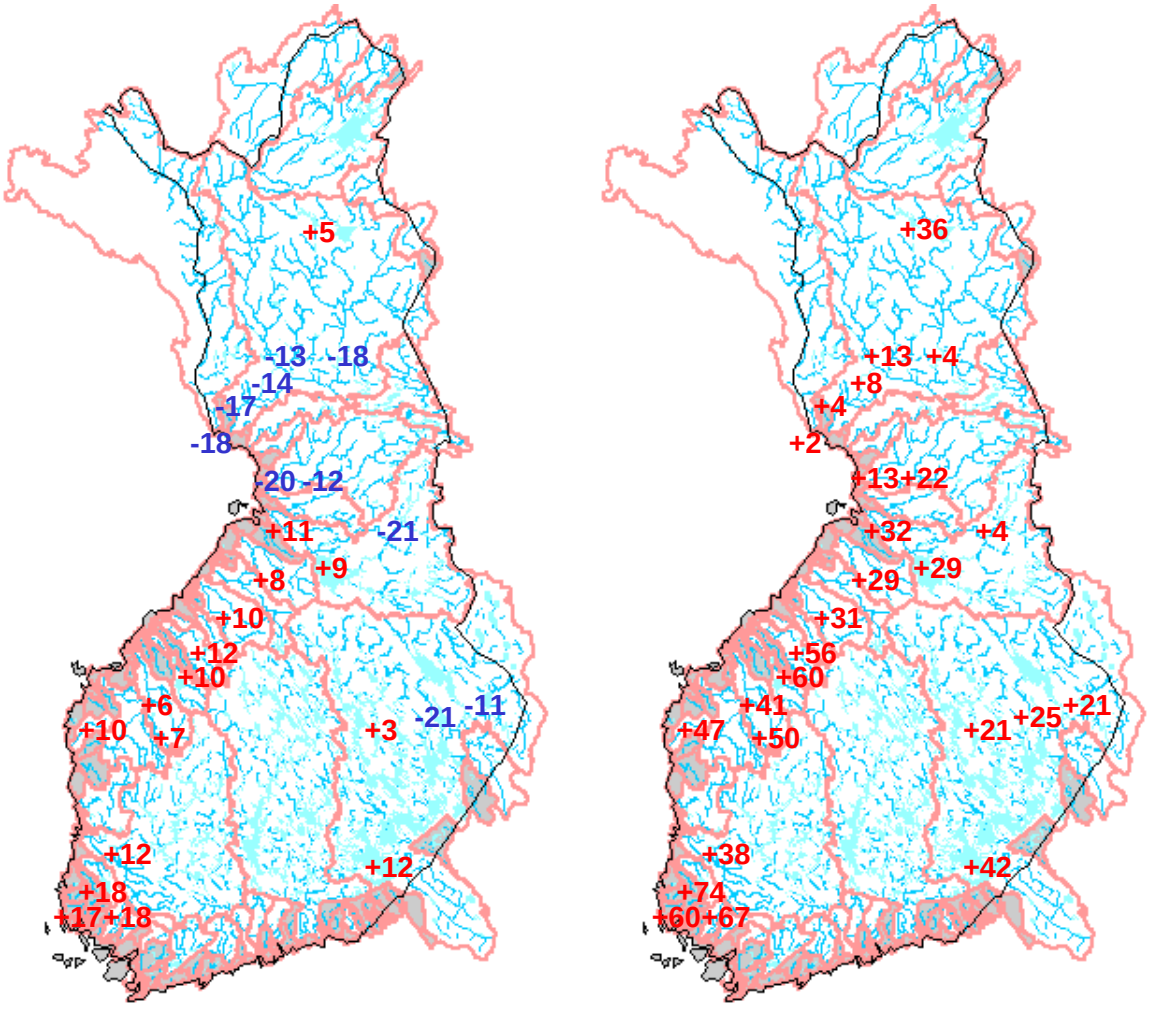

Figure 14. The estimated change (%) in design floods of P-dams compared to present situation. Smallest future floods (left) and largest future floods (right).

An example of the design flood calculations for the dam and reservoir of Patana in Ostrobothnia is provided here. At this site the design flood at present and in the future are both summer floods and occur during the same situation. Figure 15 and Figure 16 show the inflow to the reservoir, outflow through the dam and water level in the reservoir during the

design flood at present and in 2070-2100 calculated with HadCM2/IS92a climate scenario and larger increases in design precipitation. With this scenario the outflow increases by 60% compared with the outflow in present situation, which corresponds to the largest projected increase on this site. The water level in the reservoir rises considerably during the flood but stays below the emergency water level for the dam. Figure 17 shows the temperature and precipitation at the dam during the design flood in present and future conditions.

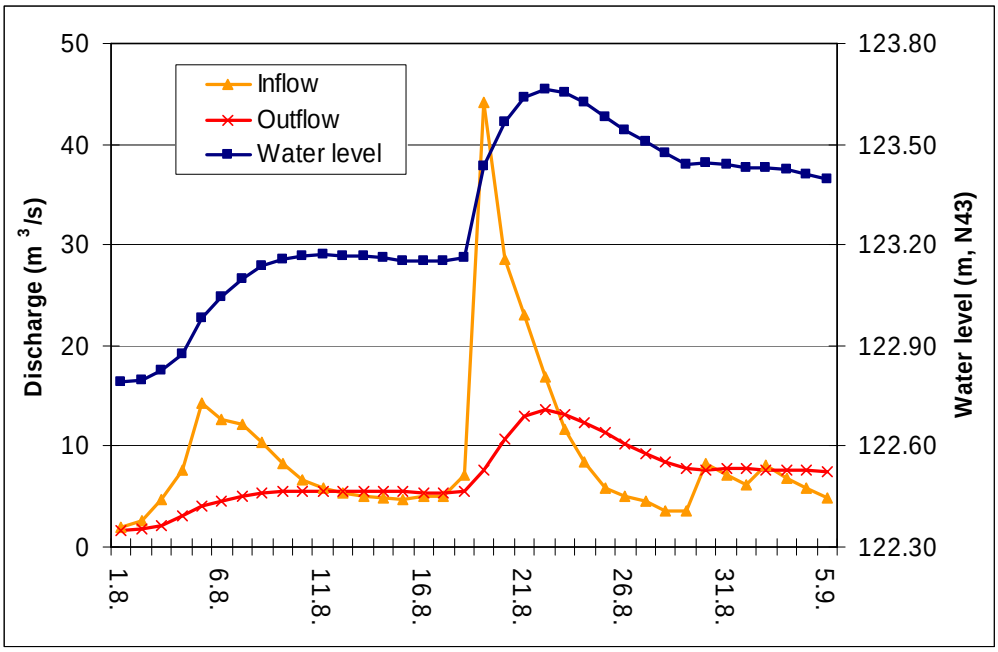

Figure 15. Design flood at Patana dam in present conditions.

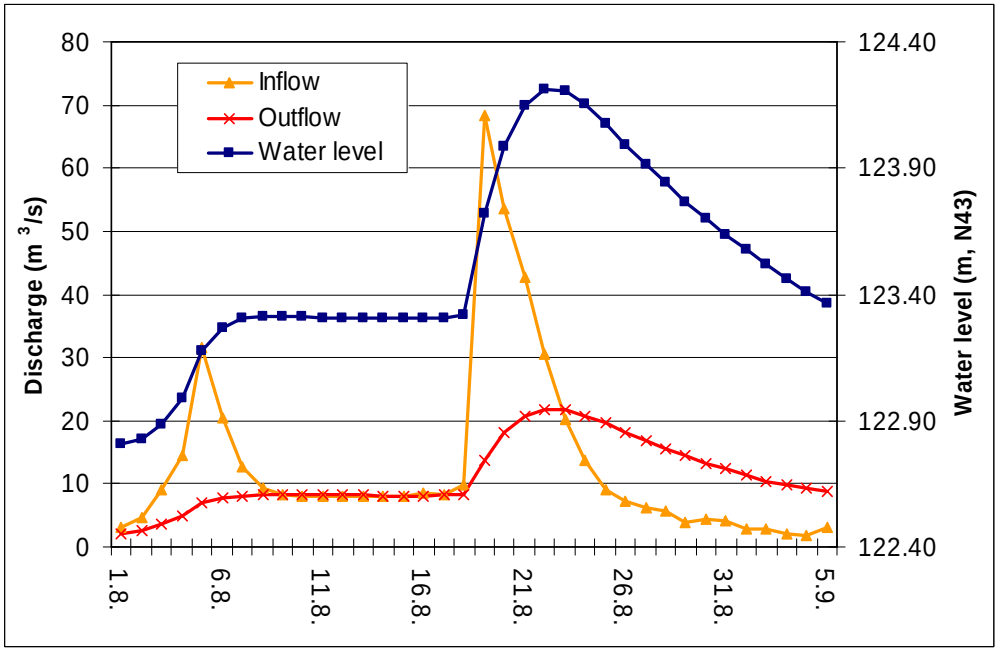

Figure 16. Design flood in conditions of 2070-2100 at Patana dam with larger increases in design precipitation and the HadCM2 climate scenario.

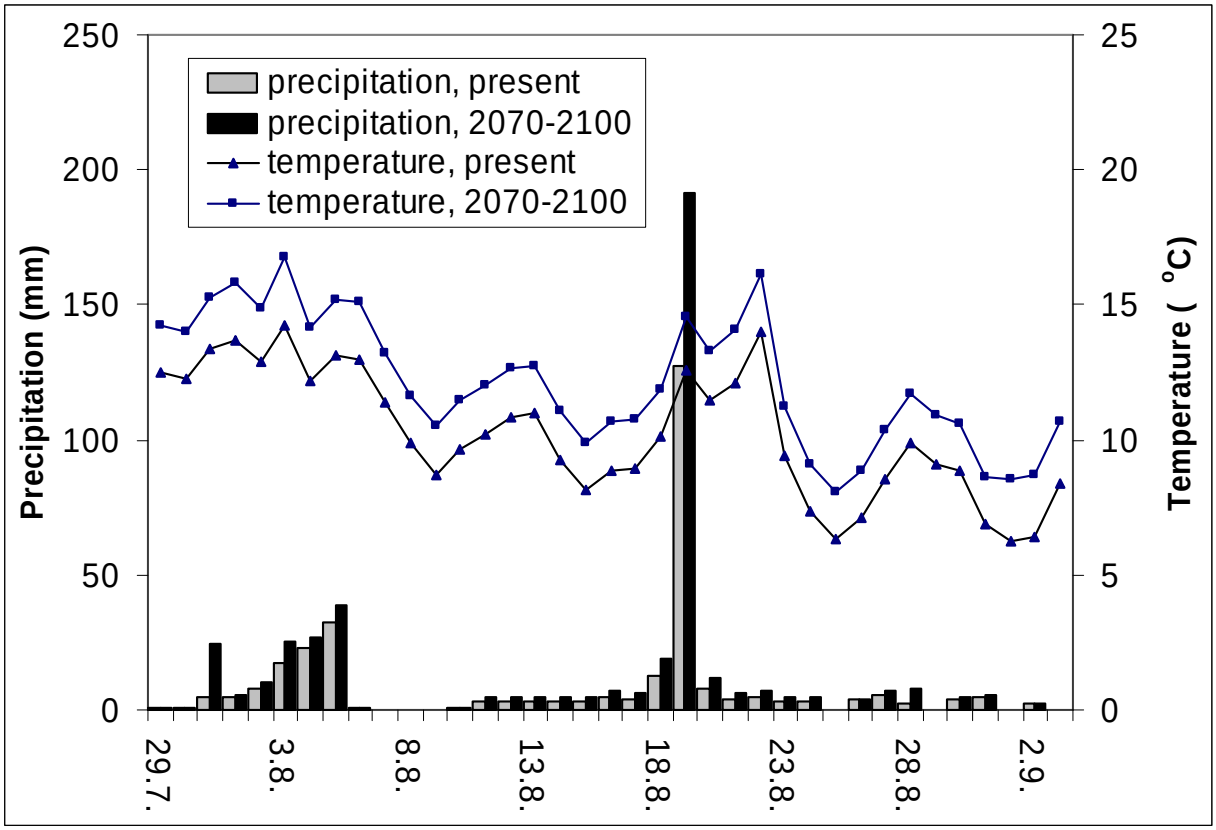

Figure 17. Temperature and precipitation at Patana dam during the design flood in present and 2070-2100 conditions. The design precipitation period occurs 11.-24.8. in both situations.

4.5.2. Adaptation measures for dam safety

The change in the magnitude and timing of runoff and floods and design floods in particular will require some adaptation measures at dams to mitigate the climate change effects. For the regulation practices to function properly in the changed situation, changes in operating rules of reservoirs and lakes will be needed. Floods that occur during summer, autumn and winter should be better taken into account in the operating rules.

Floods caused by heavy rains will probably increase due to climate change. These floods rise quickly and demand fast and efficient actions. Therefore warning systems and operating guidelines on dams should be updated to guarantee faster responses and the state of readiness for actions should be improved. The existing forecasting systems should also be developed further. More reliable weather forecasts together with more real time observations could further improve forecast accuracy and reliability.

The increases in design floods can cause needs to increase the spillway capacity of some dams before the year 2070. Although most dams can withstand some increases in design floods, on some dams, approximately 5-7 P-dams which is 15-21% of the P-dams calculated, it may be necessary to increase the spillway capacity, if the design floods increase is closer to the larger scenario presented. The cost of increase of spillway capacity depends on the type of dam in question and is between 1 000-1 000 000 euros per dam.

If rains become more intense and winds become stronger this will also effect on the stability of the dams. Heavier rains and stronger winds would increase erosion and cause more strains to the structures of dams. To adapt to this, the dams should either be repaired to be more stable or the observations of stability during storms and the ability to make emergency repairs should be improved.

The changes in the magnitudes of large floods due to climate change by 2070-2100 have already been studied from the point of view of dam safety. Further research should include more specific evaluations and plans for adaptation measures on the dams which are found to have increased risks. The future research effort should also include changes in floods with smaller return periods used for the design of low hazard dams and the changes in near future (2010-2050), especially in Northern Finland where the amount of snow may increase on the short term. The research on the necessary changes of regulation practices should include a component of dam safety. Research and development of forecasting and warning systems should be continued further to enable more faster actions when needed. Impacts and adaptation measures in dam safety are presented in the following table.

Table 5. Impacts and adaptation measures in dam safety.

Impact	Adaptation measure	Research needs
Possible increases in design floods on some dams	Increase in spillway capacity ***	Research on changes in magnitude and timing of floods *
Change of timing of design floods to summer and autumn on some dams leading to faster and less predictable floods	Changes in regulation and operating rules of reservoirs and lakes**	Research on the best regulation practice in future conditions*
	Improvement in warning systems and state of readiness for action on dams **	Development of more real time observation, forecasting and warning systems *
Changes in strains on dams due to increases in heavy rains and strong winds	Improvements on dam stability** Improved observations of stability and capability for emergency repairs**	

* 0-10 years, ** 10-50 years, *** > 50 years

4.6. Drainage and irrigation

Pajula, H.

4.6.1. Drainage situation in Finland

The cultivated land area in Finland is about 2,2 million hectares. It is expected to drop from the present by nearly 10% by 2010, but remain constant in the wide area of southern Finland (Lehtonen et al. 2002). From this area about 1,3 million hectares has a subsurface drainage system and about 600 000 hectares has been drained using ditches. However, there is still a need for ditching because in every third drained field drainage depth has been found to be insufficient (Puustinen et al. 1994). The target program of drainage is aiming to drain half of the ditch drained area (about 300 00 hectares) by 2020 (Suomen salaojakeskus 2002). This requires that main ditches are well maintained, nevertheless, in 1997, the government stopped maintenance inspections previously carried out every five years in all ditch projects financed by the government. Therefore, it is possible that many ditches are not properly maintained,

and will need to be improved in the near future. Interest for maintenance has risen in wet summers like 2004.

4.6.2. Design of drainage channels

Regardless of expected climate change, effective land drainage continues to be necessary in Finland. The design flood remains the snow melt-induced 20 year flood, HQ 1/20. Only, in southern Finland may heavy rain induced floods begin to dominate design. In autumn, with increased future precipitation, it is probable that the carrying capacity of the soil will be reduced and may be insufficient for mowing machines. Thus, in design we need to carefully define the appropriate drainage depth that allows heavy machines to move on the fields. The design flood for settled and special areas is a 50 or even a 100 year high flood, HQ. Regardless of the season, ditches and culverts must divert runoff away from the fields in a controlled way. Also, weather extremes such as rapid changes in discharge can cause erosion problems, which can be reduced by paying more attention to bed profile design.

4.6.3. Adaptation for drainage

When summer floods increase, nutrient load and sediment transport may rise causing problems in water basins. Thus in flood prevention it is necessary to develop new mitigation measures, especially flood water retention at the catchment scale. This natural method might be desirable, but the Water Act doesn't provide good opportunities for that. Thus, there may arise need tomodify the Water Act.

The basic drainage situation may become problematic due to climate change. Therefore, we should map the situation and make provision for actions. Especially fields with sunken level can be uneconomical to keep in good drainage condition. As an alternative for drainage, flood prone agricultural areas can be designated as flood areas, wetlands and buffer zones. Agri-environmental subsidies should be used for proper management of changes in land use. The following table shows needed impacts and adaptation measures in drainage.

Table 6. Impacts and adaptation measures in drainage.

Impact	Adaptation measure	Research needs
Heavy rain induced floods. Increased nutrient load and soil erosion.	Water retention in the catchment scale. ** Different kind of dike bed profiles should be considered. ** Use of flood terraces should be considered.**	Study the need of water act changes to establish water retention basins more easily to a private land.* We should develop natural bed profile models for designers.*
Condition of main ditches for drainage is reduced.	We should map the situation of main drainages and evaluate the need for restoration.**	

* 0-10 years, ** 10-50 years, *** > 50 years

4.6.4. Irrigation in Finland

In Finland, the main need for irrigation is due to the precipitation deficit in early summer and frost prevention of some plants. So far, in farming irrigation is needed only occasionally. Irrigation is important in gardening and special plant farming. Since 1995, the European Union has supported a new method called controlled irrigation, which has become common in Finland. The method is suitable for flat areas and very permeable soils. Based on a survey in 2000, it is possible to irrigate, with existing equipment, around 88 000 hectares of fields and

gardens. The greatest water demand for irrigation has been in the south-west and southern Finland where there has been a water deficit during dry summers in the 1990s'. Farming of special plants has increased the need for irrigation, and this will probably increase further in the near future.

4.6.5. Adaptation for irrigation

Expected longer and drier summers are very likely to cause problems for agriculture. Reduced soil moisture and increased evaporation will increase the need for irrigation. It is likely that there will be a lack of irrigation water in some areas. Adaptation requires new reservoirs for irrigation water, changes in regulation practices or new water tanks. There are only a few irrigation ponds in Finland. Some of them have been built for the town of Siuntio in south-west Finland. New environmental friendly irrigation methods are needed to save water. Also the number of controlled irrigation system should be further increased, so that ground water irrigation could be used more often. Table 7 shows impacts and adaptation measures in irrigation.

Table 7. Impacts and adaptation measures in irrigation.

Impact	Adaptation measure	Research needs
Dry summers are causing water deficit in some areas.	We should change regulation practices.* We should use controlled irrigation systems more often*	We should study the action needed against water deficiency.* We should develop new irrigation methods.**
Lack of irrigation water.	New water reservoirs should be built. ***	We should survey the possibilities to construct new water storages and supply systems.*

* 0-10 years, ** 10-50 years, *** > 50 years

4.7. Restoration and management of inland waters

Sammalkorpi, I., Keto, A. and Jormola, J.

4.7.1. The need for restoration

Restoration consists of corrective measures in the lake which are carried out in addition to preventive measures in the watershed area (Seppänen 1973). Finnish lakes are typically shallow and have a relatively high humic content. Some 30% of the total lake area is subject to water level regulation. The need for lake restoration also reflects these special features (Keto et al. 2004). The greatest need derives from two linked problems that particularly impede the recreational use of lakes. Algal blooms and other problems of eutrophication takes place due to internal and/or external nutrient loading, paludification due to shallowness and deviations from natural water level fluctuation. On the national level, the negative effects of acidification have remained at a clearly lower level than in Sweden or Norway, e.g. since the humic water in Finnish lakes has a good buffering capacity and the amount of acid precipitation has been lower.

The minimum number of lakes in need of restoration was estimated to be over 1300 in a national inquiry conducted in 1998 (Turunen and Äystö 2000). Their total area was larger than 6000 km², the average area of listed target lakes was 4.5 km² and the median 0.9 km². The predominant problems were related to eutrophication: algal blooms, oxygen depletion and other water quality problems, and paludification (peat bog formation). A preliminary

estimate of the costs of restoration of these lakes was c. 200 million euros (Turunen and Äystö 2000).

Flood control, drainage and hydro power use, formerly also timber floating, have been the main reasons for the poor state of some rivers in Finland. Fisheries have been the main interest for river restoration projects. There is also an increasing concern for enhancing the ecological diversity of small streams, which have been straightened and dredged in drainage works for agriculture, forestry and urban development, because they have a great importance for natural reproduction of migratory fish. Improving the quality of water in agriculture, forestry and peat mining is an essential part of the management of drainage basins. In urban areas the interest in recreation and a healthy urban environment has placed increasing demands on restoration.

4.7.2. Restoration methods and their use

The nutrient loading from point sources was reduced by more than 90% from the 1970´s to the 1990´s and today the average P-reduction in sewage treatment plants is 94% (Niemi et al. 2004). This has been a necessary prerequisite for successful restoration of Finnish lakes. Although correct and sufficient in-lake measures improve water quality in the short term, the need to further decrease the external loading from non – point sources to enable sustainable restoration results is still continuously emphasised. Authorities in charge of funding require that this is also recognised in project plans.

From 1970 to 1995, the most common methods were aeration, macrophyte control and rising of water levels. In recent years (1998-2002), the focus has shifted (Keto et al. 2004). The most frequently used restoration methods to improve water quality, i.e. to reduce internal phosphorus loading are today biomanipulation and aeration. Macrophyte removal, dredging and rising of water level are applied to reduce overgrowth or improve the access to the lake. There has been an increasing need to manage the shoreline since free time settlement is now expanding also to less optimal e.g. overgrowing shores.

The volume of lake restoration has increased from approximately 20 projects (1970-1995) to approximately 45 projects per annum (1998-2002). This is largely due to the initiative of and independent restoration actions by water area owners and other beneficiaries (e.g. fisheries regions), which has been encouraged by the environmental authorities since 1997. Consequently, the use of labour-intensive restoration methods, such as mechanical control of macrophytes and manual mass removal of cyprinids have also become quantitatively the most frequent.

Improved understanding of the structure and function of the lake ecosystem has particularly promoted biomanipulation by selective fish removal and reinforcement of piscivorous fish (Sarvala et al. 1984; Keto and Sammalkorpi 1988; Horppila and Kairesalo 1990; Horppila et al. 1998; Kairesalo et al. 1999; Sarvala et al. 2000; Jeppesen and Sammalkorpi 2002; Lepistö et al. 2003; Olin et al. 2005). However, in eutrophic lakes of the agricultural areas high clay turbidity and the potentially important role of invertebrate predators in the pelagic foodweb may confound the effects of the traditional fish removal approach (Horppila 2005). Also the important role of aquatic plants is still inadequately recognised.

Emerging restoration methods (see Ulvi and Lakso 2005) include the chemical precipitation of nutrients with aluminium chloride either in the sediment or, with a liquid treatment, both in

the water column and sediment. The method has been successfully applied in a hypertrophic shallow lake). Phosphorus stripping with gypsum containing Fe as an ingredient has also given promising results in a small stratified lake. Exhaustive temporary drainage which has been applied in some shallow lowland lakes of the western coast is an efficient way of consolidating the sediment. It also provides dry work areas for shoreline restoration. The mechanisms of these methods as well as the role of their effect on submerged plants and fish stock in their success have not yet been fully explored. Their better understanding would be beneficial e.g. since a large scale fish kill took place. The total drainage also indicates a total fish removal. A more detailed knowledge of gaining synergy by combining certain methods would help in predicting the impact and maintaining the restoration result.

In the policy of river management, the need of combining restoration goals with other interests is considered in Finland, applying environmental river engineering principles in all river management. (Jormola et al. 2003). Most river sections, especially rapids, which were dredged for timber floating purposes, have already been restored by placing back dredged stones and by creating spawning habitats of gravel (Yrjänä 2003). Sedimentation basins, wetlands, filter stripes and buffer zones for river bank and flood prone areas have been created, directing subsidies for agriculture and forestry for environmental purposes.

4.7.3. Expected climate-induced changes in restoration

The need for restoration and management measures will increase in the future. Climate change will have direct and indirect impact on the predominant restoration needs by favouring eutrophication: algal blooms, foodweb changes, oxygen depletion and other water quality problems. It favours cyprinids which benefit from and maintain the effects of increasing nutrient runoff at the expense of economically valuable and most piscivorous fish species. Increased discharges in winter and the expected warmer temperatures and longer growing season may also accelerate overgrowth in littoral zones, shallow lakes or bays of large lakes and increase the amount of decomposing organic matter. All these changes set an increasing emphasis on the capacity to mitigate the impacts by management and restoration measures. The need for mitigation of the impacts of climate change by lake restoration will grow in the future.

As summer floods are expected to increase, the normal land use of floodplains will be affected. To avoid flooding by sufficient discharge capacity, removal and management of vegetation in floodplains must be considered. Through increasing discharges, more erosion control will be needed.. Wetlands and floodplains with balancing function should be created. As also dry periods will be more common, low discharge rates may cause difficulties for fish and recreation of rivers. Bed structures must be adopted to low discharges.

4.7.4. Adaptation to climate change

The changes in lakes caused by increasing nutrient runoff and higher temperatures by the climate change are predictable. Also the tools to mitigate the effects are available in lake management. If the magnitude of increased management need caused by climate change is predicted and there is common interest to cover the additional costs, the effects of climate change in lakes can be counteracted.

It is of crucial importance to continue changes in land use of forestry and agriculture to decrease the external nutrient loading. Also stormwaters may be locally important. In lakes we need more information about the effects of the changing climate on the ecosystem to

facilitate effective and correct use of restoration methods. Nutrient balance calculations from many lakes emphasise that the effect of internal loading in summer often exceeds the amount of annual external loading (Knuuttila et al. 1994; Ekholm et al. 1997). Internal loading has a central role for phytoplankton biomass of lakes. It can not be combated by inlake measures alone since increasing external nutrient loading also increases the risk of internal loading. In addition to the well recognised anaerobic conditions of the hypolimnion or foodweb, internal loading takes place in shallow lakes also in aerobic conditions as a result of physical and chemical processes. It is uncertain if these can be affected in any other way than reducing the external loading.

As for eutrophication problems it is, however, also encouraging that two important reasons for internal phosphorus loading which may increase due to climatic change − development of anaerobic conditions in the hypolimnion and effects of dense cyprinid dominated fish populations − can be combated cost effectively with Finnish know how (e.g. Saarijärvi and Lappalainen 2005 for aeration and Turunen et al.1997; Horppila et al. 1998; Sarvala et al. 2000; Olin et al. 2006 for fish removal). A linear increase of phytoplankton biomass by increasing nutrient concentrations is not inevitable (Shapiro 1979; Carpenter et al. 1995; Sarvala et al. 2000). This was found when the phytoplankton biomass was reduced by biomanipulation in Lake Vesijärvi (e.g. Horppila et al. 1998; Kairesalo et al. 1999) and in Lake Tuusulanjärvi (Lepistö et al. 2003). The decrease of phytoplankton biomass by 50% and a simultaneous reduction of the average phosphorus concentrations by 20-30% found in these two lakes matches well with the findings from biomanipulated European lakes (Jeppesen and Sammalkorpi 2002). This remedy is available also to mitigate the effects of climate induced eutrophication. Increase of turbidity may confound the premises of a foodweb manipulation (Horppila 2005).

Increasing external nutrient load, higher summer temperatures and longer growing season will most likely increase the problems of overgrowth of macrophytes. This may locally have favourable foodweb effects but also the unfavourable effects to recreational use will probably increase. The need for macrophyte removal will grow among water area owners. We need new tools for shoreline management.

In connection with river restoration, expected increase of summer floods and drought periods must be taken in account in land use of river valleys and formation of bed structure. For retention of increasing flood discharges, flood prone areas should be designated as flood areas if danger is to be avoided for inhabitants. Extensive agriculture, like changing cereal production into hay and grazing in flood prone areas can be recommend, which can be a positive change for water quality and river ecology. Flood areas and wetlands serve as sedimentation sinks for solid particles in river water. Sufficient room for high discharge in adjacent flood areas is needed. Increasing discharges may need consideration of erosion control in river banks. Applying ecohydraulics is needed for calculation of high discharge performance of flood terraces with vegetation in summer. For low discharges, diversified river bed structure, with rather narrow low discharge bed and shading vegetation is favorable for fish, ensuring sufficient stream velocity and cool water temperature. Table 8 shows impacts and adaptation measures in restoration and management of inland waters.

Table 8. Impacts and adaptation measures in restoration and management of inland waters.

Result of climate change	Impact on lakes and rivers	Adaptation needed in management/restoration	R&D-need
Increase of runoff in winter and annually	+/-Longer ice-free period Seasonality of water level fluctuation changes - Flooding, drying out in summer.	May locally decrease the oxygen problems in shallow lakes? Update of monitoring programmes? Flood areas for retention Flood terraces for high discharges	Monitoring and modelling Eco-hydraulics
Increase in nutrient load	- Higher potential productivity in summer: algae, biomass of cyprinids - Higher nutrient store in sediments, internal loading	Intensified lake management: aeration in deeper lakes, fish management and/or control of macrophytes in shallow lakes Higher internal loading Buffer zones, wetlands	Predictability and sustainability of mgmt measures Threshold levels of loading? Experiments and model calibration
Higher summer temperatures	+ Increase in growth of macrophytes, cyprinids, pikeperch and cyanobacteria - Decrease in salmonids, perch	Intensified lake and fisheries management: control of macrophytes, removal of cyprinids, other foodweb management Bed structure for low flow Shading buffer stripes	Intensified case studies and modelling Habitat hydraulics
Higher turbidity	+ favors cyprinids and cyanobacteria, - less submerged macrophytes, pike and perch	Intensified lake and fisheries management: removal of floating and emergent macrophytes Flood areas and wetlands for agricultural and urban stream management	Effects of turbidity on management measures Experiments and model calibrations

4.8. Droughts

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Climate models project that summers are likely to be somewhat drier and longer than at present. As a result, the water level in small lakes and groundwater levels will probably be lower during summers (Figure 6). Increased evapotranspiration and lake evaporation in spring and early summer is also harmful. Fortunately, minimum summer soil moisture values in southern Finland are currently so small that the increased evaporation cannot cause considerable further reduction during dry summers. Additionally during the summer the groundwater level will decrease.

4.8.1. Impacts of drought

The impact of a drought and related severe weather was a reality for Finland and the surrounding areas in both 2002 and 2003. A study carried out at the Finnish Environment Institute (SYKE) was an effort to examine these impacts on water use, power production, agriculture, water traffic, forest, buildings (Figure 18) and environment (Silander and Järvinen 2004). The drought did not just cause significant economic damage to the regional economy but also to the fish habitat in hundreds of lakes. In addition, thousands of households suffered from water scarcity, and a lot more carbon dioxide was released into the atmosphere than normally because part of the hydropower deficit was substituted using coal-fired power plants. The recent drought in Finland cost more than 100 million euros. The study targeted one of the main aspects of drought mitigation and planning which is the assessment of who and what is vulnerable and why. The identification of drought vulnerability is an essential step to address the impact of climate change.



Figure 18. Damaged foundation under repair in Helsinki (Photo: Jari Silander 12.8.2003).

This exceptional 2002-2003 drought in southern and central Finland lasted 9 months. A previous exceptional hydrological drought, that covered the entire country, was between 1940 and 1942, lasting nearly 16 months. Average annual discharge from Finland dropped, in the recent drought, from 3200 m^3s^{-1} to 2100 m^3s^{-1}; in 1941 it was only 1600 m^3s^{-1}. The groundwater level dropped in southern Finland by about 0,5 -1,5 meters. Annual precipitation was less than 400 mm in some areas.

The recent drought resulted in water shortage and made it necessary to transport water to thousands of households and farms in rural and other sparsely populated areas. The low groundwater level caused problems to many buildings (foundations) and sewage pipe lines (leakage). Due to lower water levels inland water traffic suffered in shallow areas and created problems for cottagers. It is also known that higher water temperatures reduce water quality. This caused some damage to the recreational use of water courses. Additionally, water shortage in the Nordic countries reduced hydroelectric power generation and doubled the price of electricity (on the stock market) for a short time. Drought also doubled the number of forest fires and increased the risk of pest outbreaks. Crop production dropped only a little due to the fact that drought was mainly during autumn and winter, even though the summer was very warm. During a drought, fisheries may also be at risk, and future climate change is thought likely to affect some species sensitive to changes in water temperature. However, only minor impacts were observed during 2002 and 2003. Total costs by each sector are shown in Table 9.

Table 9. Estimated damage of the drought in years 2002 and 2003 in millions on euros.

Area of impact	Estimated damage (millions of euros)
Water supply and sewerage	8*
Hydropower production	50**
Agriculture	15
Forestry	2
Building	25
Inland water traffic	0,5
Recreational use of water course	1
Total	~102

* Doesn't include cost to the water supply companies.

** Estimated value based on additional cost due to the use of more expensive energy sources. Note, that hydropower production is expected to increase slightly, see section 4.4.

4.8.2. Adaptation for drought

To mitigate the impact of a drought, more power lines may be required as well as a larger market area than Scandinavia (with a large dependence on hydropower), to avoid high electricity prices in the near future. Another challenge concerns maintaining CO_2-levels at 1990 levels, as required under the Kyoto Protocol. Building damages can mainly be avoided by requiring piling in clay areas and monitoring timber piled buildings. In the water supply sector, existing wells need to be kept in good shape, because municipal water plants may not always be able to deliver water to all households. To prevent sewerage pipeline breakages during droughts, new methods of installing these pipes should be introduced. In agriculture, farming practices may need to be revised especially in areas of high sensitivity for rainless periods. Inland water traffic problems can mainly be avoided by dredging channels and partly by introducing new regulation practices. We should also be able to estimate groundwater levels in a changing climate. Improvements in water quality may be required by oxidizing the water in shallow lakes.

5. Conclusions and recommendations

The most important effect of climate change on hydrological regimes in Finland is the change in seasonal distribution of runoff. Winter runoff is expected to increase considerably due to an increase in snowmelt and rainfall, while spring floods are estimated to decrease in southern Finland. The risk of heavy rainfall events probably increases, with more intensive erosion and carbon losses from soil to water. Summers are expected to be warmer and longer, thus drought risk is expected to increase. Therefore, risk from future extreme events such as heavy rainfalls and heat waves can be very significant. A warmer climate according to scenarios is expected to enhance acidification and eutrophication by increasing leaching of major nutrients to watercourses. The most affected areas in coastal waters are at the southern and south-western coasts, due to the efficient cultivation and lack of lake retention at coastal basins. Thus adaptation measures are needed to both improve water quality and to improve preparedness against extremes.

A series of recommendations in terms of adaptation from different water sectors were identified:

- Administration should regularly estimate and if necessary update recommended building elevation levels, design precipitations and flood return periods. Also they should regularly e.g. update flood maps for sensitive areas and flood mitigation plans.
- Revision of regulation permits is needed in many water courses to improve the opportunities to adjust the regulation practice to changing hydrological conditions, such as increased winter floods, decreased spring floods and increased occurrence of extreme dry conditions and increased possibility for frazil ice floods.
- Designated water retention areas in a catchment scale should be considered, not only by considering flood waters but also taking into account bird habitats and their performance for sedimentation and nutrient removal.
- In order to find the best means for flood mitigation watercourses should be considered as entities.
- Climate change for hydropower will include changes in the planning and operation practices of power plants.
- Warmer summers would require to ensure water supply quality as well as quantity, e.g. by repairing network leaks, connecting networks or setting up alternative water intakes.
- Storm water systems should be increasingly piped in separate sewers instead of combined sewers.
- Adaptation requires changes in land use. The forest management practices increasing erosion should therefore be kept under control e.g. by better planning of supplementary forest drainage works, by introducing lighter forest soil treatment methods, and by avoiding cutting works if there is not enough frost in forest soil.
- The use of nitrogen/phosphorus fertilizes in agriculture may have to be reduced to counteract increased leaching losses due climate change. Changes in the cultivation practices are needed. Improved planning, for preparedness for water quality changes during severe flood and drought events, is needed.
- We should reduce present nutrient loading to coastal water by cutting loads from national non-point sources and from other major foreign sources.

- The increases in design floods can cause needs to increase the outflow capacity of certain dams.
- Aeration, management of macrophytes and foodweb management by mass removal of cyprinids are widely used in management of lakes in Finland today. They are also available to prevent the unfavorable effects of climate change on Finnish lakes in addition to measures reducing the external loading from the drainage area.

A series of research needs were also identified:

- At a national level, new lake regulation patterns should be developed and tested, especially to scope better with increased winter and reduced summer runoffs. The analysis of economic, social and ecological impacts of different regulation policies is crucial as well as frazil and ice jam effects on watercourse and regulation in changing hydrological conditions. The regulation permits, which revision would be most important, should be identified and prioritized.
- Integrative studies, which look at the ecological controls and human influence on the vulnerability of water to climate change and corresponding increasing demands for lake and coastal management, are needed.
- Assessment of combined impacts of changes in climate and land use in forested catchments by using integrated catchment models is needed.
- How to adapt to increased frequencies of algal blooms – concerning lake and marine ecosystems and recreation need to be studied in more detail.
- Studies that focus on understanding and defining critical thresholds (critical floods) in water resource systems are needed.
- Development of real time observation and forecasting systems of groundwater levels, available for groundwater utilities, is needed, within next ten years or so to better overcome longer drought periods.
- Regular research on changes in magnitude and timing of floods and droughts is essential in water resources management.
- We should develop natural bed profiles for designers to reduce erosion of drainage systems during extreme precipitation events. The hydraulic design criteria for storm water drainage systems should also be revised.

More extreme weather requires better adaptation.

6. Acknowledgements

We would like to acknowledge financial support from the Finnish Environmental Cluster Research Programme, coordinated by the Ministry of the Environment. We are grateful to Professor Tim Carter for commenting on our work and also to all those who have contributed their expert advice on this study.

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Documentation page

Publisher	Finnish Environment Institute	Date June 2006
Author(s)	Jari Silander, Bertel Vehviläinen, Jorma Niemi, Anna Arosilta, Tanja Dubrovin, Jukka Jormola, Ville Keskisarja, Antton Keto, Ahti Lepistö, Risto Mäkinen, Markku Ollila, Heikki Pajula, Heikki Pitkänen, Ilkka Sammalkorpi, Merja Suomalainen and Noora Veijalainen	
Title of publication	CLIMATE CHANGE ADAPTATION FOR HYDROLOGY AND WATER RESOURCES	
Parts of publication/ other project publications		
Abstract	The most important effect of climate change on hydrological regimes in Finland is the change in seasonal distribution of runoff. Winter runoff is expected to increase considerably due to an increase in snowmelt and rainfall, while spring floods are estimated to decrease in southern Finland. In northern Finland spring floods are expected to increase during the next few decades due to increased snowfall, but then to decline over the longer term with continuous warming. Yearly runoff is estimated to change from –5 % to 10 %. Decreases are predicted for catchments with a large lake surface which enhance lake evaporation; increases are through winter runoff. In winter excess water from snowmelt and rainfall can cause winter floods, especially large central lakes Saimaa, Päijänne and Näsijärvi will be more frequently flooded. Extreme runoff events are projected to be more frequent due to increased maximum precipitation. Impacts and adaptation to these effects in hydrological cycle are described in this publication	
Keywords	climate change, adaptation, impact, hydrology, water quality, water resources	
Publication series and number	Finnish Environment Institute Mimeographs 336	
Theme of publication		
Project name and Number, if any	FINADAPT A01025	
Financier/commissioner	Finnish Environmental Cluster Research Programme	
Project organization		
	ISSN 1455-0792	ISBN 952-11-2108-4 952-11-2109-2 (PDF)
	No. of pages 52	Language English
	Restrictions Public	Price
For sale at/ distributor		
Financier of publication	Finnish Environment Institute, PO Box 140, FIN-00251 Helsinki, Finland	
Printing place and year	Edita Prima Ltd, Helsinki 2006	
Other information		

Kuvailulehti

Julkaisija	Suomen ympäristökeskus	Julkaisuaika kesäkuu 2006
Tekijä(t)	Jari Silander, Bertel Vehviläinen, Jorma Niemi, Anna Arosilta, Tanja Dubrovin, Jukka Jormola, Ville Keskisarja, Antton Keto, Ahti Lepistö, Risto Mäkinen, Markku Ollila, Heikki Pajula, Heikki Pitkänen, Ilkka Sammalkorpi, Merja Suomalainen ja Noora Veijalainen	
Julkaisun nimi	ILMASTONMUUTOKSEEN SOPEUTUMINEN HYDROLOGIASSA JA VESIVAROJEN HALLINNASSA	
Julkaisun osat/ muut saman projektin tuottamat julkaisut		
Tiivistelmä	Ilmastonmuutoksen tärkein vaikutus Suomen sisävesien hydrologisiin oloihin on sen aiheuttama muutos valunnan, virtaamien ja vedenkorkeuksien vuodenaikaiseen jakaumaan. Ilmaston muuttuessa talven valunta kasvaa merkittävästi lumen sulamisen ja vesisateen lisääntymisen takia. Vastaavasti kevättulvat pienenevät etenkin Etelä-Suomessa ja Keski-Suomessa, kun lumipeitettä ei enää kerry lämpimien talvien aikana. Pohjois-Suomessa kevättulvien odotetaan kuitenkin vielä kasvavan muutaman vuosikymmenen aikana lisääntyneen sadannan takia, mutta pienenevän myöhemmin lämpenemisen edetessä skenaarioden mukaisesti. Vuosittaisen valunnan on arvioitu muuttuvan –5 … +10 %. Valunta kasvaa sadannan kasvun myötä. Etelä- ja Keski-Suomen järvisillä vesistöalueilla vuosivalunnan arvioidaan pienenevän jonkin verran järvihaihdunnan kasvun myötä. Talvella lisääntyvä lumen sulanta ja vesisadanta lisäävät talvitulvia; etenkin suurten keskusjärvien - kuten Saimaa, Päijänne ja Näsijärvi – vedenkorkeudet tulevat nousemaan talvella nykyistä ylemmäksi. Sadetulvien arvioidaan yleistyvän rankkasateiden kasvun myötä myös kesällä varsinkin pienissä vesistöissä. Toisaalta pidentynyt kesäkausi tuo tulleessaan myös kuivien kesien mahdollisuuden etenkin Etelä- ja Keski-Suomessa.	
Avainsanat	ilmastonmuutos, sopeutuminen, vaikutukset, hydrologia, vesivarat, veden laatu	
Julkaisusarjan nimi ja numero	Suomen ympäristökeskuksen moniste 336	
Julkaisun teema		
Projektihankkeen nimi ja projektinumero	FINADAPT A01025	
Rahoittaja/ toimeksiantaja	Ympäristöklusterin tutkimusohjelma	
Projektiryhmään kuuluvat organisaatiot		
	ISSN 1455-0792	ISBN 952-11-2108-4 952-11-2109-2 (PDF)
	Sivuja 52	Kieli englanti
	Luottamuksellisuus Julkinen	Hinta
Julkaisun myynti/ jakaja		
Julkaisun kustantaja	Suomen ympäristökeskus, PL 140, 00251 Helsinki	
Painopaikka ja -aika	Oy Edita Ab, Helsinki 2006	
Muut tiedot		

ISBN 952-11-2108-4
ISBN 952-11-2109-2 (PDF)
ISSN 1455-0792

The most important effect of climate change on hydrological regimes in Finland is the change in seasonal distribution of runoff. Winter runoff is expected to increase considerably due to an increase in snowmelt and rainfall, while spring floods are estimated to decrease in southern Finland. In winter, excess water from snowmelt and rainfall can cause winter floods, and the large central lakes Saimaa, Päijänne and Näsijärvi are expected to be more frequently flooded. Extreme runoff events are projected to be more frequent due to increasing maximum precipitation. High flows and intense rainfall increase soil erosion, chemical leaching, urban and livestock wastes and nutrients from catchments into watercourses and coastal waters. On the other hand, the possibility of dry periods is also expected to increase, due to a lengthening of the summer. During low flows, increased concentrations of bacteria, harmful algae and toxins are common. This report describes impacts and adaptation to these effects in relation to the hydrological cycle.

Ilmastonmuutoksen tärkein vaikutus Suomen sisävesien hydrologisiin oloihin on sen aiheuttama muutos valunnan, virtaamien ja vedenkorkeuksien vuodenaikaiseen jakaumaan. Ilmaston muuttuessa talven valunta kasvaa merkittävästi lumen sulamisen ja vesisateen lisääntymisen takia. Kevättulvat taas pienenevät etenkin Etelä-Suomessa ja Keski-Suomessa, kun lumipeitettä ei enää kerry lämpimien talvien aikana. Talvella lisääntyvä lumen sulanta ja vesisadanta lisäävät talvitulvia; etenkin suurten keskusjärvien - kuten Saimaa, Päijänne ja Näsijärvi – vedenkorkeudet tulevat nousemaan talvella nykyistä ylemmäksi. Sadetulvien arvioidaan yleistyvän rankkasateiden kasvun myötä myös kesällä varsinkin pienissä vesistöissä. Voimistuvat rankkasateet ja niiden seurauksena voimistuvat tulvat lisäävät eroosiota, ravinnekuormitusta ja haitallisten aineiden huuhtoutumista vesistöihin. Toisaalta pidentynyt kesäkausi tuo tulleessaan myös kuivien kesien mahdollisuuden etenkin Etelä- ja Keski-Suomessa. Pienten virtaamien aikana vesistöjen bakteerimäärät ja haitallisten aineiden pitoisuudet kasvavat ja leväkukinnat voivat yleistyä.

This report is also available at the FINADAPT Web site:
http://www.ymparisto.fi/syke/finadapt or from www.environment.fi/publications
Finnish Environment Institute, Box 140, 00251 Helsinki, Finland, tel: +358 20490123

FINADAPT (Assessing the adaptive capacity of the Finnish environment and society under a changing climate) is a consortium co-ordinated at the Finnish Environment Institute (SYKE). It is part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment.

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Research Programme