Long-term changes in lake and river systems in Finland

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Finland possesses 72 waterway systems of over 200 square kilometres in size. The five largest of them account for the majority of the country's surface area. Furthermore, there are almost 188,000 lakes of more than five ares in size. Altogether 9.9 percent of the surface area consists of water. The lakes have been created over the last 10,000 years or so, either through the emergence of their basins from beneath the ice sheet of the last glaciation or, in most cases, through isolation from the Baltic basin. In this article, the post-glacial history of the main watercourses and lake basins in Finland and the effects of recent human activity on them and on the quality of their water are examined.

On account of the uneven pattern of land uplift, most of the large waterway systems, such as the Saimaa, Päijänne, Näsijärvi, and Puula watercourses of the Lake District, have altered their outflow in the course of time, some of them more than once. The majority of these hydrological changes took place in the interval 8500–4500 BP. In the case of Lake Oulujärvi and Lake Vanajavesi, a transgression that has been going on for thousands of years has led to rises in water level of as much as 10–15 metres. In the case of Lake Höytiäinen, uncontrolled erosion of the outflow channel in connection with an effort at lowering the water level led to a sudden drop of almost ten metres. Elsewhere, the changes in outflow channels meant that the main watershed in the Lake District shifted up to 300 kilometres in a SE–NW direction. Meanwhile, human activity has led to the total or partial drainage of about 3,000 lakes in different parts of the country. About four-fifths of the inland water area in Finland is of good or excellent water quality and only five percent is of moderate or poor quality.

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Introduction

The present lakes and rivers of Finland have arisen during post-glacial times, i.e., within the last 10,000 years or slightly more. The oldest lakes are those that developed in the supra-aquatic areas of North Karelia, where the land began to emerge from beneath the ice sheet before 11,000 BP (Hyvärinen 1973). The small lakes and upper reaches of the river systems in the south began to take shape only after the water level in the Baltic Ice Lake had dropped to that of the surrounding ocean, around 10,300 BP (Tikkanen 1989; Korhola & Tikkanen 1996). The majority of the lakes are in fact considerably younger than 10,000 years of age and have been isolated from various stages of the Baltic to form independent basins as a result of land uplift. The youngest of all are still in the process of rising from the sea and being cut off as separate basins on the recent coastal area (Tikkanen 1990).

As the pattern of land uplift in Finland has been an uneven one, the land surface has gradually tilted, causing many lakes to flood their banks and alter their direction of outflow. In places even whole watercourses have altered their direction of flow with time, and considerable changes have taken place in the location of the principal watersheds. The majority of the changes in outflow channels occurred in the interval 8500–4500 BP, but the youngest known natural change, in the outflow channel of the Längelmävesi lake system, occurred as late as 1604 AD (Blomqvist 1926; Jones 1977). Numerous small lakes have become shallower in the course of time as a consequence of the deepening of their outlet channels and the accumulation of bottom sediments, and some had even become filled in entirely. In some cases, rivers have been dredged, lake levels have been lowered artificially, or lakes have been converted into regulation basins for hydroelectric power schemes. Water quality has also varied greatly in many waterway systems, mainly as a consequence of human action in recent times.

Nowadays Finland has almost 188,000 lakes of over five ares in area, of which about 56,000 are over one hectare (Raatikainen 1985a; Raatikainen & Kuusisto 1990). The total lake area, 33,522 square kilometres, amounts to 9.9 percent of the country's surface area. The largest individual lakes are Great Saimaa (4,380 km^2), Inari (1,050 km^2), and Päijänne (1,038 km^2). The deepest point, in Lake Päijänne, is as much as 95.3 metres, but the mean depth of the Finnish lakes is no more than 7.2 metres and all the water contained in them would fit into the nearby Lake Onega in Russian Karelia without difficulty (Tikkanen 1990).

In the central parts of the Lake District water accounts for more than half of the surface area, but the highest numbers of individual lakes are to be found in the Inari district of Lapland. There, one area of 100 square kilometres, corresponding to a single basic map sheet (1:20 000), has been calculated to contain as many as 1,466 separate lakes (Kuusisto 1985). The lakes are linked together by rivers to form watercourses, the vast majority of which flow into the Baltic Sea. Finland thus has 72 watercourses that are more than 200 square kilometres in area. The five largest watercourses account for the majority of the country's surface area.

This article will provide a brief description of the post-glacial history of the watercourses in Finland and a discussion of the effects of human influence on this history and on the condition of the lakes and rivers. Separate mention will be made of certain large lakes that have been of major significance for the history of all the other watercourses.

Changes in outflow direction in the Lake District watercourses

When the last parts of the great watercourses that make up the Lake District of Finland became isolated from the Baltic basin about 8000 BP, the majority of them originally flowed to the northwest into the Gulf of Bothnia. The largest of all was a labyrinthine watercourse that skirted round the present-day Saimaa and Päijänne systems and had its outflow over a threshold in the present-day Lake Kotajärvi in Pihtipudas into the headwaters of the Kalajoki River (Saarnisto 1971b; Ristaniemi 1982, 1987; Eronen 1990; Tikkanen 1990). The watershed extended as far as the First Salpausselkä marginal formation south of the Ancient Lake Saimaa and Ancient Lake Päijänne (Fig. 1).

The central lake of this vast watercourse, the Great Lake of Central Finland, was formed by the Ancient Lake Saimaa and Ancient Lake Päijänne, which were almost at the same level and were separated only by a threshold of Selkäydenjärvi at Pielavesi in North Savo (Saarnisto 1970). This large lake had much broader expanses of open water than the current watercourses, especially in the north, and its surface was more than 20 metres above the present level (Saarnisto 1970; Tikkanen 1990; Virkanen & Tikkanen 1998) (Fig. 2).

As the land in the area of the Kotajärvi threshold was rising faster than that in other parts of the lake basin, the water level in both the Saimaa and Päijänne systems rose in the course of time. This transgression served to link new basins to them. The Great Lake reached its maximum extent about 6000 BP, at which point the rising waters broke through the Heinola esker in the south to form a new outlet channel via the Kymijoki River. By that stage the water level at the southern tip of Lake Päijänne had risen about 20 metres (Saarnisto 1971a). Once the breach had been made at Heinola, the Kotajärvi threshold dried up and the basins in the north began to be isolated as separate lakes, while water levels in Lake Päijänne subsided similarly. This meant in turn that the watershed in the south shifted some 300 kilometres further north in places, becoming established in the Suomenselkä area (Fig. 1).

The rising waters of the Ancient Lake Saimaa similarly began to seek new outlet channels. With time, two such channels opened up, through the small lakes of Matkuslampi near Ristiina (about 6000 BP) and at Kärjenlampi near Lappeenranta (around 5500 BP). These then operated simultaneously for some time, at which point the outlet channel to the north in Pielavesi dried up. The waters of the Saimaa area were still flowing into

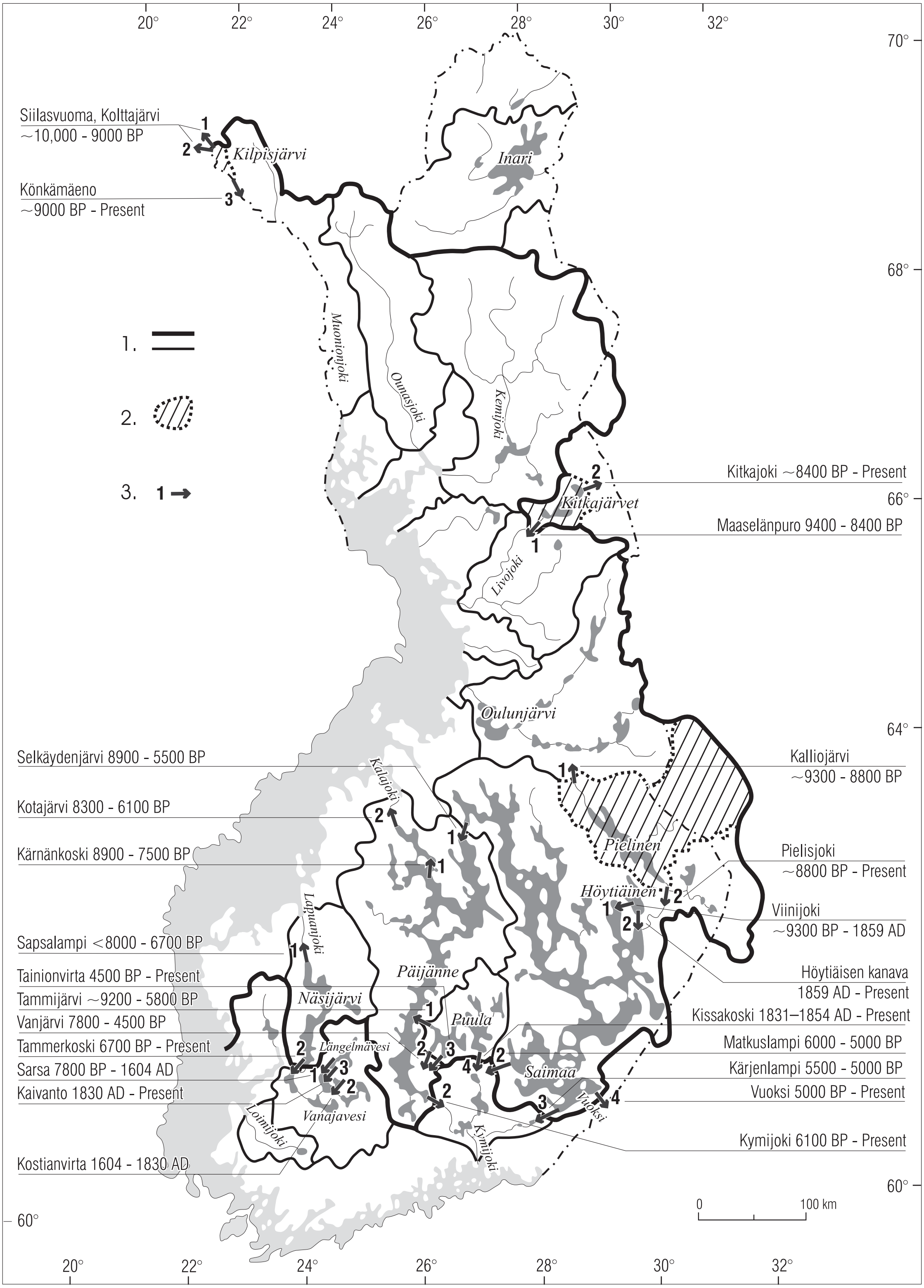

Fig. 1. Coastline of Finland and the main waterways systems and watersheds around 7000 BP. (1) Principal watershed and watershed between major drainage basins; (2) Change in watercourse before 7000 BP; (3) Outflow channel and basin number. According to Tikkanen (1999: 41).

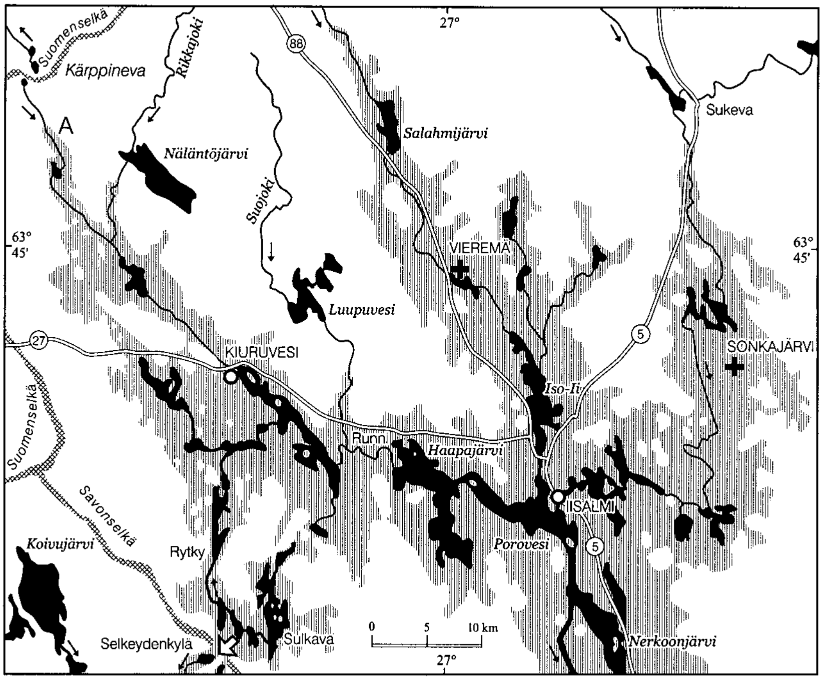

Fig. 2. Extent of the Great Lake Saimaa in northern Savo region about 8000 BP (shaded). Recent watercourses are indicated in black. The thick arrow in the Savonselkä watershed shows the outlet threshold of the ancient lake.

the Gulf of Finland via the Kymijoki River at that time. The present outflow channel arose around 5000 BP, when these waters broke through the First Salpausselkä formation and began to flow through the Vuoksi channel into Lake Ladoga (Saarnisto 1970) (Fig. 1).

The Kokemäenjoki watercourse likewise differed greatly in early times from what is known today. The waters of Lake Näsijärvi and those that flowed into it had their original outlet in the north, passing into the headwaters of the Lapuanjoki system at Alavus (Tolvanen 1924; Tikkanen & Seppä 2001), while the watershed in the south was located at the Pyynikki esker in Tampere. Thus the waters of Lake Kyrösjärvi and the Loimijoki River still formed a separate watercourse leading to the sea around 7000 BP (Fig. 1). As the Ancient Lake Näsijärvi was also transgressive, however, the water level in its southern parts rose, opening a new outlet channel at Tammerkoski around 6700 BP (Tikkanen & Seppä 2001). This meant at the same time that many of the watercourses leading into Lake Näsijärvi were redirected to the Kokemäenjoki system, although the area crossed by the present-day river of that name still lay largely beneath the Litorina Sea.

The lakes that make up the Puula watercourse between Päijänne and Saimaa have shifted their outlet channel in two stages, first from the north-west to the west and later to the south-west, where the present channel, Tainionvirta, opened up at Koskipää near Hartola around 4500 BP (Tikkanen 1995). Lake Puulavesi was artificially redirected in 1831–1854 to flow into the Mäntyharju watercourse by the construction of a canal at Kissakoski, although a small stream had already developed at that site as a result of the transgression, functioning as a natural outlet channel (Hellaakoski 1928).

Early changes in outflow and continuous transgression

Even before the time of the changes in the directions of flow of the major watercourses of the Lake District, a number of transgressions had taken place that had led to alterations in outflow channels and significant reshaping of drainage basins. One water body affected in this way was Lake Pielinen in North Karelia. It had its original outflow in the north-west, at the threshold in the Suo-

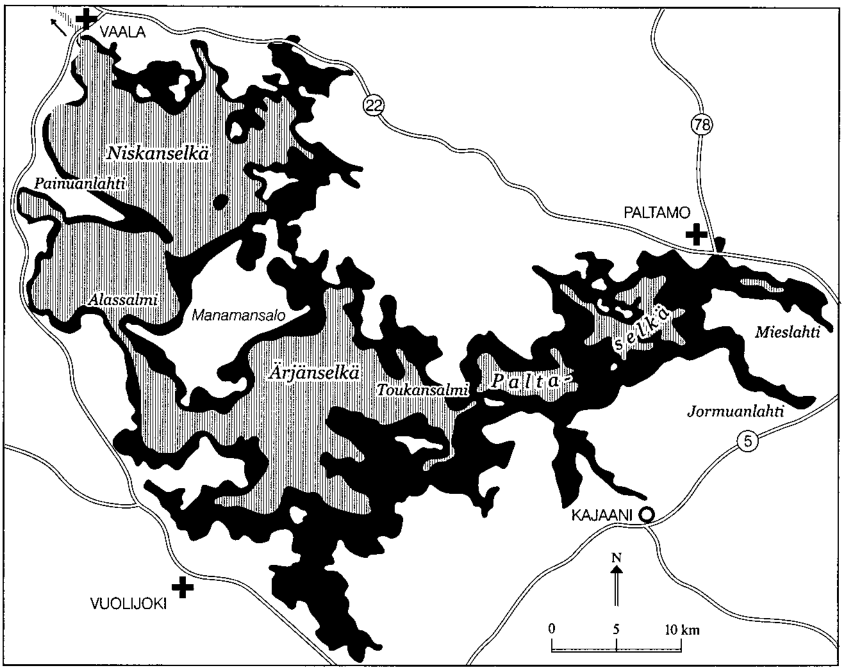

Fig. 3. Lake Oulujärvi during isolation about 8400–8300 BP (shaded). Areas submerged after that time are indicated in black. (Generalized from Koutaniemi & Keränen 1983)

menselkä watershed marked by Lake Kalliojärvi, so that it belonged to the Oulujoki drainage basin. This threshold dried up around 8400 BP, when the waters of the transgressive lake opened up a new channel through the esker of Uimaharju at the south-eastern end. The lake had, in effect, been an independent basin for no more than about 500 years at that stage (Hyvärinen 1966; Saarnisto 1971b), although the basin had been occupied prior to that time by an ice lake, which in its later stages had been connected to the Sotkamo Ice Lake via the Kalliojärvi valley (Sauramo 1928; Miettinen 1996; Saarelainen & Vanne 1997). Once a passage had been made through Uimaharju and the channel of the Pielisjoki River had been established, Lake Pielinen and its extensive drainage basin were transferred from the Oulujoki watercourse to the Vuoksi system (Fig. 1). The subsequent regression then cut down the length of the lake by some 40 kilometres and reduced its surface area considerably. The effect on water levels was such that the Kalliojärvi threshold is nowadays about 66 metres above the lake surface.

The Kitkajärvi lakes in Kuusamo arose in a supra-aquatic position about 9400–9500 BP on the retreat of the ice sheet, and their waters drained away over a threshold of Maaselänpuro and into the Livojoki River in the Iijoki basin. As the outflow channel was located in an area of greater land uplift, the Ancient Lake Kitka was transgressive from the outset. The rising water eventually reached the height of the present threshold on the outflow into the Kitkajoki River in the east. The result was a long bifurcation stage, before the Maanselkä threshold finally dried up around 8400 BP (Heikkinen & Kurimo 1977). At the same time the watershed shifted entirely to a point west of the lakes and the whole basin was transferred from the Iijoki watercourse, flowing into the Baltic, to the Koutajoki watercourse, which flows into the White Sea (Fig. 1). The shoreline of the Ancient Lake Kitka, which is clearly distinguishable in the terrain, is now more than ten metres above the present lake level in the west.

Correspondingly, the outflow channel from Lake Kilpisjärvi in Enontekiö led over the watershed to the Atlantic Ocean, via the valleys of Skibotn and Stordalselva, at a time when the ice sheet closed off the various possible channels to the south (Fig. 1). The ice lake in question was about 50 kilometres long at its maximum and its shoreline ran about 20 metres above the present level of the lake in the final stage (Taipale & Saarnisto 1991). As the ice margin retreated southeastwards, an outflow channel opened up first into the Lätäseno valley and, finally, via the present-day route into the Muonionjoki River. According to Taipale & Saarnisto (1991: 295), the ice lake stage lasted about one thousand years and came to an end around 9000 BP.

There are many more large lakes in which major changes have taken place in the course of time, even though the result may not have been an alteration in outflow channel. If the threshold was located in an area of faster land uplift, a transgression will have taken place that will have raised the water level considerably in the course of the millennia. One case in point is Lake Oulujärvi, which was isolated from the Ancylus Lake stage of the Baltic around 8300–8400 BP. Its outflow threshold has always been situated in the same place, at the north-western end, although the land rises faster here than elsewhere in the basin. The resulting transgression has raised the water level at the eastern end of the lake by as much as 15 metres (Koutaniemi & Keränen 1983), so that the original series of basins have combined to form a single large lake. Its surface area has doubled since the time of its isolation (Fig. 3).

A similar history may be traced for the Vanajavesi basin on the Kokemäenjoki watercourse. Vanajavesi's outlet channel has remained at the north-western end throughout its history as a lake. Having been isolated from the Baltic around 7500 BP, Lake Vanajavesi has inundated vast areas of mire on its shores (Auer 1924, 1968; Saarnisto 1971b) and its transgressive surface has risen by about ten metres at the southern end. Likewise, Lake Pyhäjärvi in Säkylä and Eura, which was isolated from the Baltic around 5600 BP (Eronen et al. 1982), has been transgressive ever since. Flooded peat areas are to be found on its bottom at the south-eastern end, even though the water level has been lowered artificially by about two metres.

Regulation and drainage of lakes

The inhabitants of Finland began to take advantage of the watercourses by the fourteenth century at the latest, harnessing the rapids to provide power for flour mills, planing machines for producing splints and roofing shingles, and, later, sawmills. In many cases this meant the building of dams to raise the water level. Otherwise the smaller streams could only be used during the flood season. As various forms of water power have been developed, the rivers have been modified to a stepwise profile and the lake levels have been regulated. Nowadays about a third of the total area of natural lakes in the country, i.e., some 10,200 square kilometres, is subject to regulation. About one half serves the needs of hydroelectric power, one quarter flood control, and one quarter water supplies. Also, about 20 reservoirs have been constructed for regulation purposes, with a combined surface area of 800 square kilometres (Raatikainen 1985b), and about 100 square kilometres of water areas in bays off the estuaries of rivers have been closed off to form freshwater basins (Raatikainen 1985b; Ollila 1986). The largest reservoirs are those of Lokka (417 km^2) and Porttipahta (214 km^2), created by damming the headwaters of the Kemijoki River. There are also many small, shallow lakes in danger of growing over in which the water level has been raised to improve their ecological condition (Fig. 4).

Water is usually stored in the regulated basins during the spring flood season and during rainy spells in summer and autumn, and released from them in considerable quantities in winter and at times of dry weather. Regulation has thus been used to make substantial alterations in the rhythm of discharge of many rivers. The Oulujoki River, for example, no longer has any natural high water period in May and June, as discharge is at its lowest at that time on account of the amounts of water released during the winter, so that virtually its whole storage capacity can be filled with the flood water. Sometimes quite extensive and complicated systems of canals and dams are required to ensure an adequate water supply to reservoirs (Tikkanen 1990).

Much of regulation of watercourses is designed to minimize flood peaks. The river systems of Ostrobothnia, having few lakes, show great variations in water levels. Here, floods are common. Efforts have therefore been made to prevent flooding by dredging the channels in order to ensure that the water flows more quickly, raising the banks so that the water will not flood onto the surrounding fields, and storing the water in reservoirs and natural basins. On the other hand, dredging of the headwaters of river systems, in particular, together with the ditching of mires and forests, has accelerated the movement of the wa-

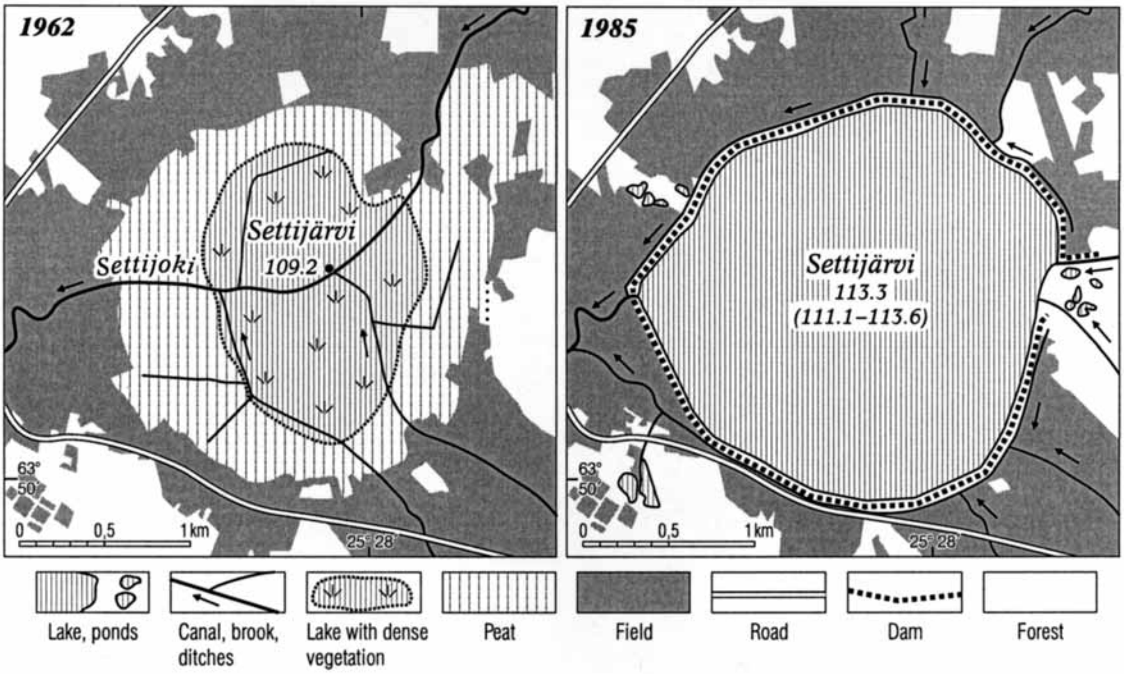

Fig. 4. Lake Settijärvi in Haapajärvi before and after damming and regulation.

ter and made the lower reaches of the rivers more susceptible to flooding. Finland still has some 70,000 hectares of land that are in need of flood protection (Kytö 1986).

Settlement has always tended to be concentrated beside the rivers and lakes, but human influence on these waterways remained minimal until the mid-eighteenth century (Anttila 1967; Vesajoki 1982). At this time began a protracted period of some 200 years during which almost 3,000 lakes were drained either totally or partially and innumerable others underwent at least some lowering of their water level (Huttunen 1981; Raatikainen 1985b). This drainage, for the purpose of either avoiding flooding or obtaining more arable land, was accomplished by lowering the threshold or digging an entirely new outlet channel (Fig. 5).

The first known artificial lowering of a lake level in Finland was undertaken by Lauri Nuutinen in the parish of Eno in 1743, when he and his family dug a drainage channel through the esker that restrained the waters of Lake Sarvinginjärvi (Palmén 1903; Vesajoki 1982). Once the water had entered the new channel it began to deepen rapidly, so that the old outlet dried up completely. Eventually all that was left of a lake eight kilometres long was a chain of small pools joined by a river that flowed across fertile fields of former bottom gyttja. When others saw that the meadows created by lowering the lake level produced a good crop of hay, an enthusiasm for draining lakes spread rapidly across North Karelia and Central Ostrobothnia.

The draining of lakes reached its peak in the nineteenth century, but the practice continued into the twentieth century. Numerous small pools were also drained in order to dry paludified forests on their shores. The land gained in the drainage process did not always prove suitable for cultivation, however, as sometimes all that was revealed was a rocky bottom. It was not uncommon, either, for the drainage process to remain incomplete, leaving an expanse of useless boggy ground or a water basin that would soon become overgrown (Tikkanen 1990: 249).

The work of shaping watercourses in the desired manner did not always go according to plans in other respects, either. Many drainage operations ended with the water getting out of hand and deepening the newly dug channel far more than had been intended, leading to an excessive drop

Fig. 5. Drained and cultivated basin of Lake Tainusjärvi at Jurva, western Finland. (Author's photo, 07/95)

Fig. 6. Outflow channel of Lake Höytiäinen created by uncontrolled erosion in 1859 at Kontiolahti, eastern Finland. (Author's photo, 06/90)

in the water level. The best-known example of this is the disastrous discharge and lowering of Lake Höytiäinen in 1859 (Fig. 6), when the lake level fell by 9.5 metres and about 170 square kilometres of former lakebed became dry land (Sauramo & Auer 1928; Saarnisto 1968; Vesajoki 1980a, 1980b, 1982). In a similar case, the collapse of a dam in a channel being dug through the esker of Kangasalanharju in 1830 lowered the surface of Lake Längelmävesi by two metres very rapidly and laid bare some 30 square kilometres of land (Renqvist 1951).

Water quality

The effects of human activity are also clearly reflected in the quality of the water in Finland's lakes and rivers. Effluent from industry, settlements or agriculture, and also airborne deposits, have caused the ecological condition of many watercourses to deteriorate. According to a usability classification that corresponded to the situation in the mid-1990s, over four-fifths of the lake basins in Finland were nevertheless in an "excellent" (38%) or "good" state (42%), while 16 percent

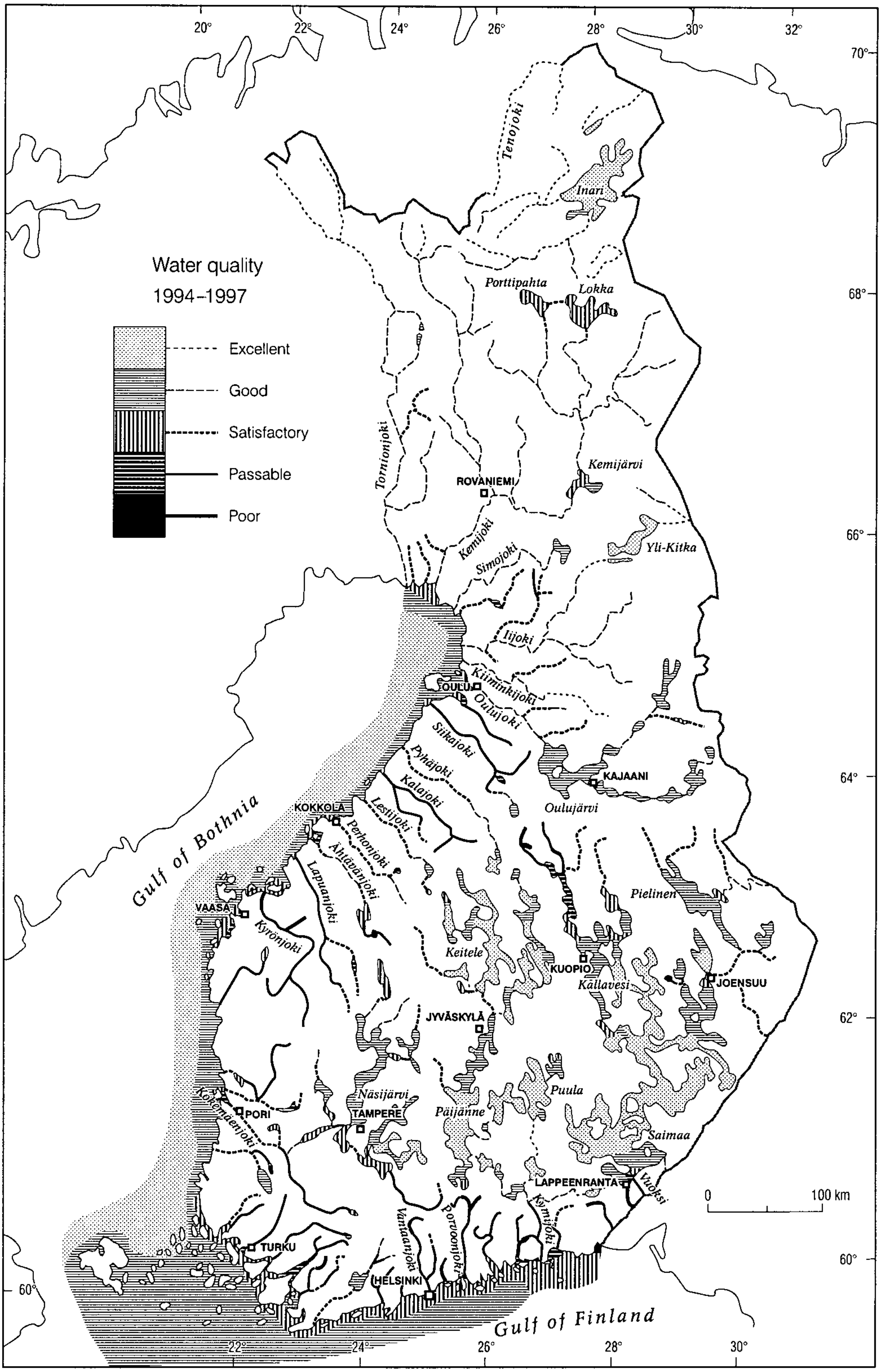

Fig. 7. Usability ratings of inland waterways in Finland in the mid-1990s (generalized from Antikainen et al. 1999).

were in "satisfactory," 4 percent "moderate" and 0.3 percent in "poor" condition (Antikainen 1999; Antikainen et al. 1999; Antikainen et al. 2000) (Fig. 7). The best situation on average is in the Lake District and in the north of Lapland (Tikkanen 1999). Particularly marked improvements have been brought about in recent years in the state of the badly polluted lakes and rivers adjacent to large industrial complexes or settlements. On the other hand, a slowly advancing process of eutrophication has affected the general condition of many lakes.

The rivers of Finland are in a distinctly poorer condition than the lakes: only two out of five are classified as "excellent" (8%) or "good" (31%), while 30 percent are "satisfactory," 29 percent "moderate" and more than 2 percent "poor" (Antikainen et al. 1999). The poorest results apply to the rivers of Ostrobothnia and the south coast (Fig. 7). The task of improving their state will be a difficult one, because activities such as fish farming, peat mining, and the diffuse loading from forestry and agriculture affect the water quality of the rivers most seriously of all.

Many Finnish lakes have characteristically been undergoing a slow process of acidification throughout post-glacial times (Alhonen 1967; Donner et al. 1978; Huttunen et al. 1978; Tolonen 1980; Tolonen et al. 1986; Korhola & Tikkanen 1991), but the trend has been accentuated by the effects of sulphur and nitrogen compounds released in the generation of energy, in industrial processes, and by motor traffic. Apart from its own pollutants, Finland receives airborne sulphur deposition from beyond its boundaries, chiefly from Russia and Central Europe. The water of acidified lakes is clear and the fish suffer from reproductive difficulties, so that there are a few lakes in Southern Finland in which acidification has reached the point where there are no fish at all. According to Forsius (1992), the estimated proportion of acidic lakes in 1987 was 12 percent of the total number of lakes but only about 0.8 percent of the total lake surface area in Finland, and more than 45 percent of the acidic lakes have been acidic already during pre-acidification times due to their high concentrations of organic matter.

As a result of recent curbs on sulphur emissions, many small acidified lakes already show signs of recovery and their pH has begun to rise, as elsewhere in Europe and North America (Stoddard et al. 1999; Mannio 2001). Nitrogen emissions continue to pose a threat, however, as these are still increasing. The large lakes in Finland have not usually been prone to acidification, because they receive various other pollutants and nutrients that neutralize the acid influx, whereas the small lakes in the headwaters of waterways systems, often located in nutrient-poor, forested areas, are more susceptible, as they have a natural alkalinity deficit. Alkalinity has also declined over recent decades in some larger watercourses such as the Kemijoki drainage basin and Lake Inari (Wahlström et al. 1992).

Mercury is another problem affecting watercourses in Finland. In some lakes in Southern and Central Finland mercury concentrations in the predatory fish are twice or three times the natural background level. Mercury enters the ecosystems through both point source and diffuse loading, from industry, the combustion of waste, agriculture, etc. Similarly, pronounced regulation of water levels, especially in small reservoirs, is likely to raise the mercury content. Mercury persists in watercourses for a long time, but there are now signs that the prevention of emissions from the wood processing industries has reduced concentrations gradually in many river and lake systems from the 1970s onwards (Wahlström et al. 1992: 304). In the same way, concentrations of other detrimental substances (notably cadmium, lead, and arsenic) in Finland's waterway systems have diminished by 20–40 percent over recent decades (Mannio 2001: 37).

Many efforts have been made to improve the condition of Finland's lakes and rivers. Where lake levels have been lowered too drastically, measures have been taken to raise them. Stretches of rapids that had been dredged are now being returned to their original state by rolling the larger rocks back into the channel. Water quality has been improved by intensifying and centralizing purification processes, and by leaving protective zones alongside river banks and lake shores, constructing precipitation basins, removing excessively lush vegetation, oxygenating deeper waters that were suffering from oxygen deficiency, and dredging bottom sediments that contain excessive amounts of phosphorus or other pollutants. Internal loading in eutrophicated lakes has been reduced by intensified fishing for cyprinids (such as roach and bream). Although there is still much room for improvement in the water quality of Finnish lakes and rivers, it can now be said with confidence that the decline in their condition has for the most part been arrested and signs of a distinctly better water quality have been observable in many areas in recent times.

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