Trends and variability in unregulated streamflow in Finland

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ABSTRACT

This paper presents long-term discharge trends and variability for thirteen time series including both rivers and lake outlets in Finland. These unregulated discharge time series were studied for the longest available period until year 2004 and for the period 1961-2004. The longest discharge time series date back to the mid-1800s. The aim of this study was to examine observed changes and variability in the Finnish discharge regime until so far. The discharge peak flow usually occur in the south in April and in the north in June. In northern Finland the maximum flow of the year is always due to snow melt, but in the southern Finland summer, autumn and winter high flows are also possible. The Mann-Kendall trend test was applied to study changes in annual, monthly and seasonal mean discharges, maximum and minimum flows and in addition the date of peak flow. The trend analysis showed no changes in mean annual flow in general, but the seasonal distribution of streamflow have been shifted. Winter, spring and minimum discharges have increased at least half of the observation sites. The magnitude of increase in winter and spring discharges was 2…10 % per decade. The spring peak has moved earlier for the third of the studied sites with magnitude of 1…3 days per decade.

KEYWORDS

Discharge, trends, variability, Finland, rivers, lake outlets

1. INTRODUCTION

Water resources are highly dependent of climatic conditions. Run-off regime is affected by both precipitation and temperature changes, as well as changes in radiation balances. Finland belongs to the so called humid zone; the major water bodies do not normally dry out. A typical feature in Finland is the abundance of water bodies, both lakes and rivers. The water situation may, however, greatly differ from year to year. Within a year, there is a considerable difference between the winter, when the precipitation is stored in the snow cover, and the summer, when a major part of the rainwater evaporates. In the long run, slightly more than half of the precipitation evaporates and little bit less than half flows into the seas from Finland. Discharge gauging is the most precise method of all water balance component measurements. Future climate scenarios predict both droughts and floods to be increased due to greenhouse effect, therefore it is interesting to examine observed changes in the Finnish streamflow regime hitherto.

There are several earlier studies concerning long-term changes in Finnish discharge regime. Hyvärinen with his colleagues has carried out most of the discharge analysis done in Finland (Hyvärinen and Vehviläinen 1981, Hyvärinen 1988, Hyvärinen and Leppäjärvi 1989, Hyvärinen 1998, 2003). Kuusisto (1992) has also studied long-term runoff from Finland. Finnish streamflow records have also been included in the Nordic runoff studies conducted by Hisdal *et al.* (1995, 2003, 2004) and Roald (1998). Effects of climate change on water resources in Finland have been presented by e.g. Vehviläinen ja Lohvansuu (1991), Hiltunen (1992, 1994), Vehviläinen and Huttunen (1997) just to mention a few anterior.

2. DATA AND METHODS

The data consist of daily mean discharges for thirteen different gauges from the different parts of the country. Both rivers and lake outlets are included in this investigation. Discharges have been determined from water level records by the rating curve method. Many of the watersheds in Finland are regulated either for water power production or flood mitigation. All the studied sites are unregulated, but some changes (land uplift, changes in land use, ditch drainage, forestry etc.) in the catchment during the years are unavoidable. because there are so many regulated watersheds, the even distribution of studied discharge sites over the country was not possible. Many of the studied lake outlets are situated in the headwaters, since the lower water bodies are regulated. The longest discharge time series in this study date back to the mid-1800s. The study sites and their locations are presented Figure 1. The observation periods, upper catchments and lake percentages are presented in Table 1.

The data were analysed until the year 2004 for the longest available period, and in addition for the period 1961-2004. Trend analysis was applied to annual mean discharges (calendar year), monthly mean and seasonal mean discharges (winter: Dec-Jan-Feb, spring: Mar-Apr-May, summer Jun-Jul-Aug, and autumn: Sep-Oct-Nov), annual maximum and minimum flows and date of the peak flow (maximum). Trends were tested statistically with the non-parametric Mann-Kendall trend test. The level of 5 % was used for the critical significance. Trend slope of the magnitude was calculated using a non-parametric Sen's slope estimator (Sen 1968).

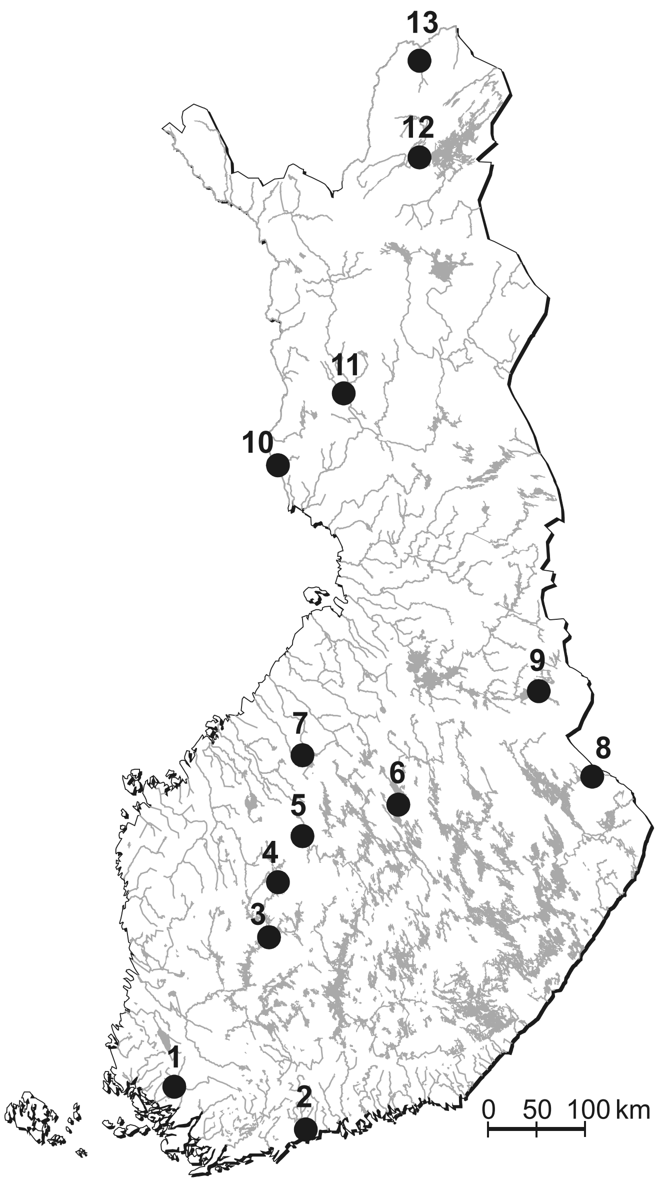

Figure 4. A map of the discharge gauging station locations used in this study.

Table 2. A list of studied rivers and lake outlets including available time period, upper catchment (F) and lake percentage (L) of discharge point.

Name		Observation period	F (km^2)	L (%)
1.	Aurajoki, Hypöistenkoski (river)	1948-2004	351	0
2.	Vantaanjoki, Oulunkylä (river)	1937-2004	1620	2.8
3.	Muroleenkoski – outlet (lake)	1863-2004	6102	12.2
4.	Kitusjärvi – outlet (lake)	1911-2004	546	9.6
5.	Pääjärvi – outlet (lake)	1911-2004	1214	7.1
6.	Nilakka Äyskoski (lake)	1896-2004	2157	17.9
7.	Lestijärvi - outlet (lake)	1921-2004	363	21.1
8.	Ruunaa – outlet (lake)	1931-2004	6259	13.7
9.	Lentua - outlet (lake)	1911-2004	2045	12.7
10.	Tornionjoki, Karunki (river)	1911-2004	39010	4.7
11.	Ounasjoki, Marraskoski (river)	1919-2004	12303	2.6
12.	Juutuanjoki, Saukkoniva (river)	1921-2004	5160	4.7
13.	Utsjoki , Patoniva (river)	1963-2004	1520	2.6

RESULTS AND DISCUSSION

2.1 Discharge regime and variability

The annual peak flow usually occurs usually in southern coast in April and in northern Lapland in the turn of May and June. In northern Finland maximum flow of the year is always due to snow melt, but in the southern Finland summer, autumn and winter annual maximum flows due to high rainfall are also possible. In the north the minimum flow of the year is recorded in the winter, but in the south both winter and summer flow minima are common. In Figure 2 monthly minimum, mean and maximum discharges for four different discharge gauges are presented. Two of the graphs present the annual discharge regime of river sites and two same for the lake sites.

There is a great variation of discharge from year to year, and especially monthly mean discharges differ greatly between the years. The variation percentage of annual mean discharge varied from 19 to 37%. It was highest in the southern river sites with a small lake percentage and a small area of the catchment. Lowest variations were recorded in northern Finland. The highest variation percentage of the monthly discharges was for February 220% in the river Aurajoki.

The driest years have been at most of the sites 1941 or 1942. The wettest year was not so evident as the drought of 1941-1942, on the contrary it varied between the sites. At many places the year 1981 was a rather wet. The ratio between the wettest and the driest year discharges varied from 3- to 6-folded.

The average ratio between HQ and MQ of each year varied from 2- to 4-fold at lake sites and from 6- to 16-fold at river sites. The ratio is highly dependent on the lake percentage; if the percentage is low, the ratio is high and vice versa.

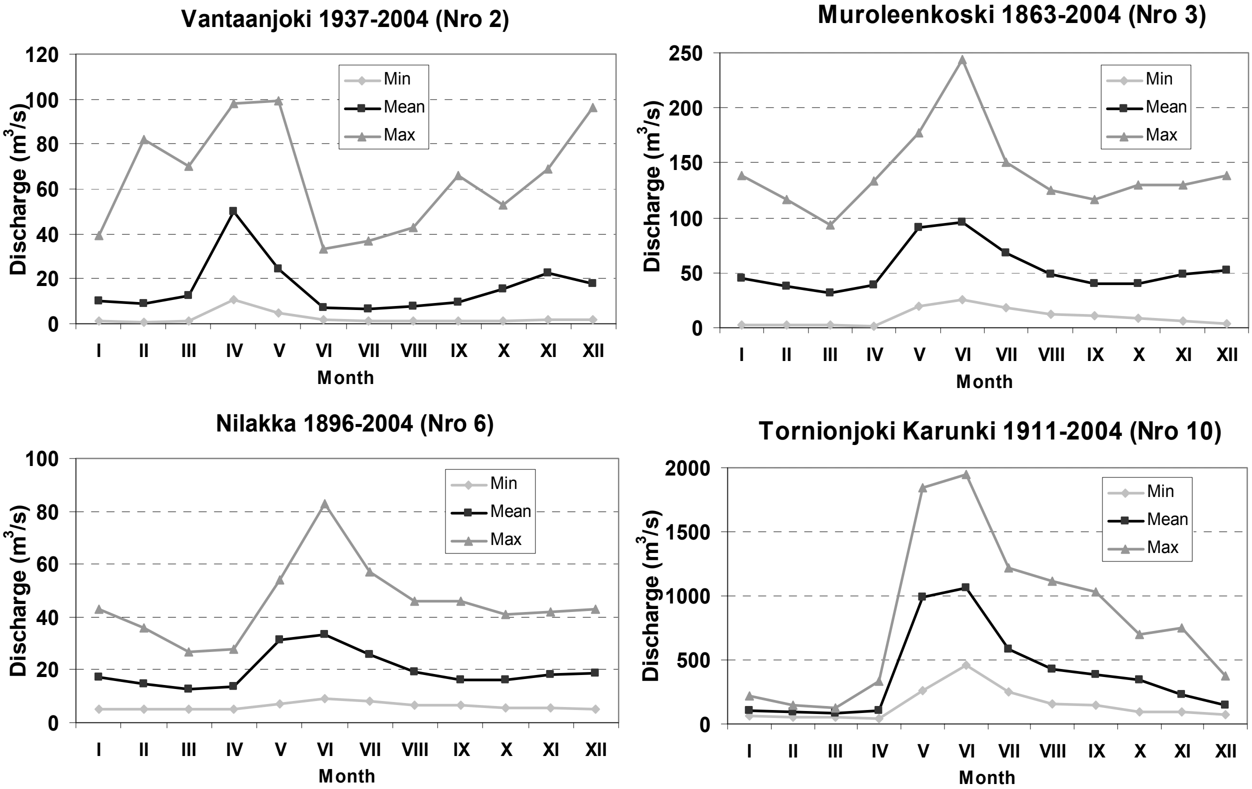

Figure 5. Monthly minimum, mean and maximum discharges for four different discharge gauges.

2.2. Trends

Statistically significant trends in streamflow for the longest possible period until 2004 and for the period 1961-2004 are shown later in Table 2. Eleven of thirteen sites (85 %) had at least some trends detected. There were more statistically significant trends for the whole observation period available than for the period 1961-2004. There were no trends for the annual mean flow in general, only one site (river Tornionjoki) had statistically significant trend for increased discharges. Neither high flows had no long-term changes. The biggest change has happened in the seasonal distribution of flow. The spring peak has moved earlier, statistically significantly at the third of the observation sites. The magnitude of trend for the timing of the peak was 1…3 days per decade. Winter and spring discharges have increased at most sites. 69 % of the time series had significant increase of discharge for spring months an 49 % for winter months. The minimum flow has increased for 46 % of the sites. The magnitudes of discharge increases were typically 2…10 % of the mean flow (of month or season) per decade. The summer flows had increased for only 15 % of the sites. In addition, 1-2 of the time series had negative trends for a few winter, spring or summer mean monthly discharges. Basically, no statistically significant trends in autumn flows were found. Time series of the mean annual discharge and the mean spring (MAM) discharge for different stations are presented in Figures 3 and 4.

Positive trends in winter discharge can be explained by milder winters during the last decades. The increased spring discharge is due to earlier spring peaks; the shift in the peak timing has increased discharges.

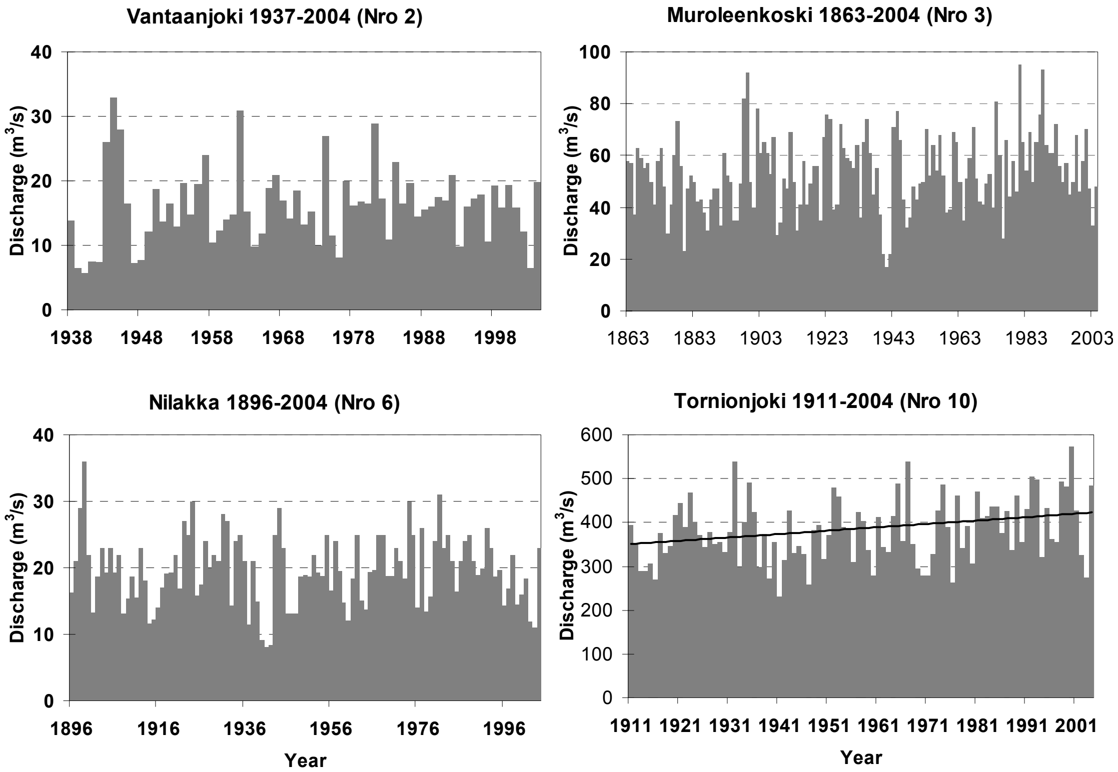

Figure 6. Mean annual (MQ) discharge (m^3/s) for four different discharge gauges.

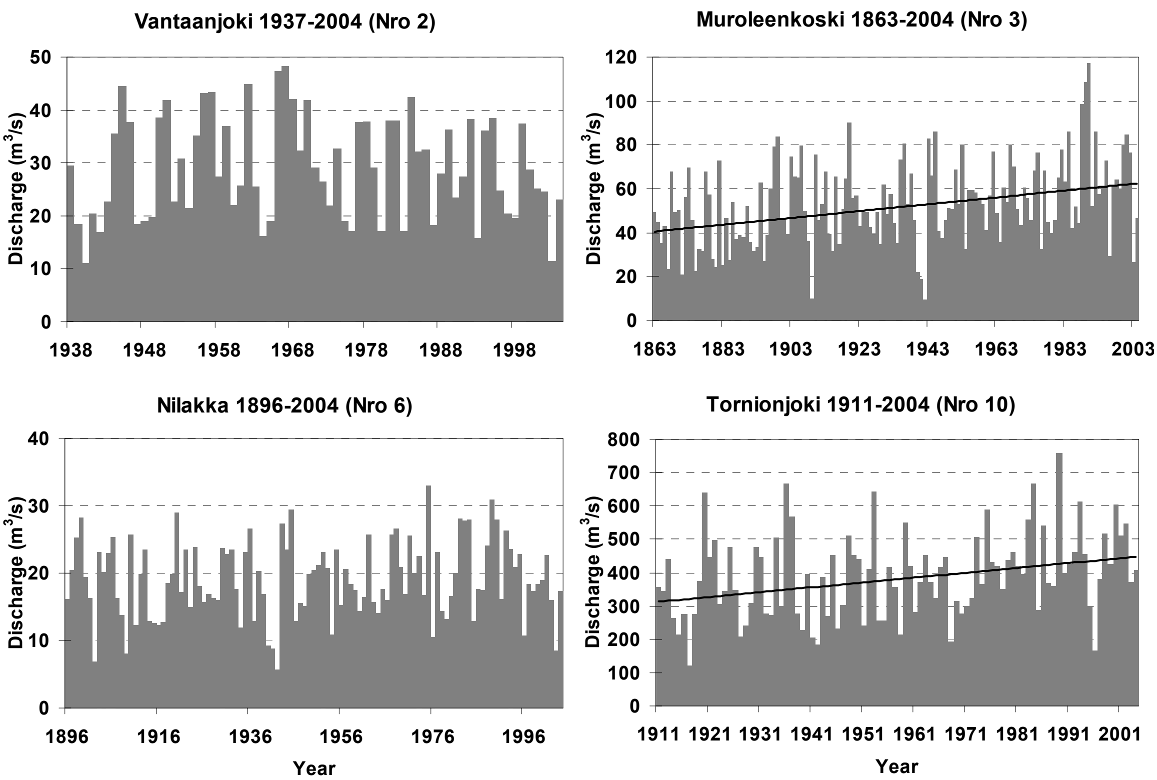

Figure 7. Mean spring (MAM) discharge (m^3/s) for four different discharge gauges.

Table 3. Statistically significant trends for monthly and seasonal mean discharges, maximum and minimum flows and peak flow dates. I-MQ means January mean discharge, II-MQ February mean discharge etc. DFJ-MQ means winter mean discharge, MAM-MQ spring mean discharge etc.

Observation site	Variable and period	+/-	p<	Trend /10 a, %
1 Aurajoki, Hypöistenkoski Period 1948-2004	II-MQ 1948-2004	+	0,05	0,1 m^3/s (5,0 %)
	III-MQ 1948-2004	+	0,01	0,3 m^3/s (9,1 %)
	VI-MQ 1948-2004	+	0,001	0,1 m^3/s (12,5 %)
	VII-MQ 1948-2004	+	0,05	0,05 m^3/s (4,5 %)
	III-MQ 1961-2004	+	0,05	0,5 m^3/s (13,5 %)
	JJA-MQ 1948-2004	+	0,05	0,1 m^3/s (9,1 %)
	DJF-MQ 1961-2004	+	0,05	0,5 m^3/s (18,5 %)
2 Vantaanjoki, Oulunkylä Period 1937-2004	I-MQ 1937-2004	+	0,05	0,9 m^3/s (8,9 %)
	II-MQ 1937-2004	+	0,001	0,8 m^3/s (9,0 %)
	III-MQ 1937-2004	+	0,01	1,0 m^3/s (8,1 %)
	VII-MQ 1937-2004	+	0,001	0,5 m^3/s (7,5 %)
	VIII-MQ 1937-2004	+	0,01	0,5 m^3/s (6,6 %)
	NQ 1937-2004	+	0,001	0,2 m^3/s (10,0 %)
	DJF-MQ 1937-2004	+	0,05	1,0 m^3/s (8,2 %)
	JJA-MQ 1937-2004	+	0,01	0,5 m^3/s (7,0 %)
	HQ (MAM) 1961-2004	-	0,05	12,7 m^3/s (10,8 %)
3 Muroleenkoski Period 1863-2004	I-MQ 1863-2004	+	0,01	1,5 m^3/s (3,3 %)
	II-MQ 1863-2004	+	0,001	1,6 m^3/s (4,3 %)
	III-MQ 1863-2004	+	0,001	1,5 m^3/s (4,8 %)
	IV-MQ 1863-2004	+	0,001	1,9 m^3/s (4,9 %)
	VI-MQ 1863-2004	-	0,05	1,6 m^3/s (1,7 %)
	NQ 1863-2004	+	0,001	0,9 m^3/s (4,3 %)
	HQ-date (spring) 1863-2004	-	0,001	1,0 d
	DFJ-MQ 1863-2004	+	0,01	1,3 m^3/s (2,9 %)
	MAM-MQ 1863-2004	+	0,001	1,6 m^3/s (3,0 %)
4 Kitusjärvi, luusua Period 1911-2004	No statistically significant trends			
5 Pääjärvi, luusua Period 1911-2004	II-MQ 1911-2004	+	0,001	0,3 m^3/s (5,9 %)
	III-MQ 1911-2004	+	0,001	0,3 m^3/s (7,3 %)
	IV-MQ 1911-2004	+	0,01	0,5 m^3/s (5,1 %)
	NQ 1911-2004	+	0,001	0,2 m^3/s (28,6 %)
	VII-MQ 1961-2004	+	0,05	0,8 m^3/s (9,1 %)
	MAM-MQ 1911-2004	+	0,05	0,5 m^3/s (3,0 %)
6 Nilakka, Äyskoski Period 1896-2004	IV-MQ 1896-2004	+	0,05	0,3 m^3/s (2,2 %)
7 Lestijärvi, luusua Period 1921-2004	III-MQ 1921-2004	+	0,05	0,05 m^3/s (2,3 %)
	IV-MQ 1921-2004	+	0,01	0,09 m^3/s (3,6 %)
	MAM-MQ 1921-2004	+	0,05	0,09 m^3/s (2,8 %)
8 Lieksanjoki, Ruunaa Period 1931-2004	No statistically significant trends			
9 Lentua, luusua Period 1911-2004	II-MQ 1911-2004	+	0,05	0,3 m^3/s (2,2 %)
	III-MQ 1911-2004	+	0,05	0,2 m^3/s (1,8 %)
	V-MQ 1911-2004	+	0,05	1,5 m^3/s (2,8 %)
	NQ 1911-2004	+	0,01	0,2 m^3/s (1,5 %)
	MAM-MQ 1911-2004	+	0,05	0,6 m^3/s (2,3 %)
	II-MQ 1961-2004	+	0,01	0,9 m^3/s (6,5 %)
	III-MQ 1961-2004	+	0,001	0,8 m^3/s (6,9 %)
	NQ 1961-2004	+	0,01	0,6 m^3/s (6,1 %)
10 Tornionjoki, Karunki Period 1911-2004	I-MQ 1911-2004	+	0,001	5,6 m^3/s (5,2 %)
	II-MQ 1911-2004	+	0,001	4,7 m^3/s (5,3 %)
	III-MQ 1911-2004	+	0,001	4,3 m^3/s (5,4 %)

	IV-MQ 1911-2004	+	0,01	3,3 m^3/s (3,2 %)
	V-MQ 1911-2004	+	0,01	36,0 m^3/s (3,7 %)
	XI-MQ 1911-2004	+	0,05	9,1 m^3/s (4,0 %)
	XII-MQ 1911-2004	+	0,001	8,2 m^3/s (5,6 %)
	MQ 1911-2004	+	0,01	7,7 m^3/s (2,0 %)
	NQ 1911-2004	+	0,001	3,5 m^3/s (4,7 %)
	DJF-MQ 1912-2004	+	0,001	6,3 m^3/s (5,5 %)
	MAM-MQ 1911-2004	+	0,01	14,5 m^3/s (3,7 %)
	HQ-date (spring) 1911-2004	-	0,01	1,4 d
	V-MQ 1961-2004	+	0,05	73,1 m^3/s (6,9 %)
	HQ-date (spring) 1961-2004	-	0,05	2,9 d
	MAM-MQ 1961-2004	+	0,05	29,6 m3/s (7,0 %)
11 Ounasjoki, Marraskoski Period 1919-2004	III-MQ 1919-2004	+	0,01	0,9 m^3/s (2,7 %)
	NQ 1919-2004	+	0,01	0,7 m^3/s (2,3 %)
	HQ-date (spring) 1961-2004	-	0,05	2,5 d
12 Juutuanjoki, Saukkoniva Period 1921-2004	I-MQ 1921-2004	-	0,05	0,6 m^3/s (2,7 %)
	HQ-date (spring) 1921-2004	-	0,05	1,2 d
	HQ-date (spring) 1961-2004	-	0,01	3,3 d
13 Utsjoki, Patoniva Period 1963-2004	II-MQ 1963-2004	-	0,05	0,3 m^3/s (6,5 %)
	III-MQ 1963-2004	-	0,01	0,3 m^3/s (7,7 %)
	NQ 1963-2004	-	0,001	0,3 m^3/s (9,1 %)

COMPARISON WITH OTHER STUDIES

There are a number of earlier studies concerning long-term changes in runoff in Finland and in the Nordic countries. Anterior studies of long-term changes in runoff or discharge regime have showed a quite similar patterns as this study do. The increase of wintertime discharge in southern and central Finland was presented first by Hyvärinen and Vehviläinen (1980). Later observations and analyses confirmed these findings (Hyvärinen 1988, Hyvärinen ja Leppäjärvi 1989, Hiltunen 1994 and Hyvärinen 1998, 2003). The Nordic studies of trends in runoff regime have revealed considerable differences in different parts of Fennoscandia (Hisdal *et al.* 1995, 2003, 2004 and Roald 1998). Mean annual discharges have been increased especially in some regions in Denmark and Sweden. Positive trends have also been found for Norway and Finland depending on the chosen time period (Hisdal *et al.* 2004). For the period 1941-2002 statistically significant trends are found for Finland probably because the first year of time period (1941) was the driest ever observed at many places in Finland. In Iceland, annual values of discharge do not show clear trends (Jónsdottir 2005). In Karelia, Northwest Russia, the river runoff has decreased during the 20th century (Filatov 2005).

Discharges are naturally highly dependent of precipitation and evaporation. Long-term changes have not been detected for the precipitation time series in Finland (Tuomenvirta 2004), although in the other Nordic countries (Sweden, Norway, Denmark, Iceland) increase have been observed (Hisdal *et al.* 2003, Jónsdottir *et al.* 2005). In Karelia, Northwest Russia precipitation has been increased during the 20th century (Filatov *et al.* 2005). The evaporation time series begin mainly in the late 1950s in Finland, thus such long time series as precipitation and discharge records, are not available for the Class A Pan evaporation. However, for the period 1961-1990 no trends were reported by Järvinen and Kuusisto (1995). Neither precipitation nor evaporation show remarkable long-term trends in Finland. Regardless, the changes in the streamflow have been observed in Finland. However, the annual mean flow in unregulated streams has not changed in Finland in general. The main issue is the change in the seasonal distribution of discharge regime.

CONCLUSIONS

Thirteen Finnish discharge time series of unregulated rivers and lake outlets were examined in this study. The timing of high flow in the rivers varies from April to June from the south to north, respectively. The low flows are recorded in the north in the winter and in the south typically in wintertime or in summertime. Typical variation of annual mean discharge was 20…40 %. It was highest in southern river sites with a small lake

percentage and a small area of the catchment. Lowest variations were in northern Finland. The ratio between annual high flow and annual mean flow varied from 2- to 4-fold in lake outlets and from 6- to 16-fold in rivers.
Trends of time series were analysed in order to find changes in the historical records. Mean annual, monthly and seasonal discharge trends as well as changes for the extreme values were calculated by the non-parametrical Mann-Kendall trend test. Mean annual flows showed no changes, but the seasonal distribution of flow has changed in most places investigated in this study. The spring peak has moved earlier for the third of the sites. The change has been 1…3 days per decade. Trend analysis showed that the winter, spring and minimum discharges have increased at least half of the observation sites. The magnitude of observed increase in the monthly or seasonal discharge was typically 2…10 % per decade. Positive trends in winter discharge can be explained by milder winters with increased winter precipitation during the last decades. The increased spring discharge is due to earlier spring peaks caused by warming during the spring time; the shift to earlier peak flows has increased discharges. There were no statistically significant changes in autumn streamflow in general.

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