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Estimating Lake Evaporation with Floating Evaporimeters and with Water Budget

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A short review of the four lake evaporation research projects in Finland is given. Three of the lakes studied are situated in southern Finland and one in the north. One of the lakes is deep in Finnish terms and the rest are shallow. The methods used and the results obtained in 1971-1974 are also discussed in this paper. The results are compared with those of a Class A pan station. Two of the research projects have already been reported in more detail in IAHS publication No. 109.

Introduction

It is possible to measure or compute the amount of water evaporating from a lake surface in several different ways. Because it is difficult to measure lake evaporation directly, indirect methods have to be used in some cases. This in turn may reduce the reliability of the results. Even though the instrumentation has been improved considerably in recent years, instrumental limits restrict the measurement of the factors regulating evaporation. The cost of measurements may also be a limiting factor. To increase the reliability of the results it is often necessary to use several methods of determining evaporation in parallel.

In this paper the results of the determination of lake evaporation in Finland in 1971-1974 are presented and different methods compared. Of the four lakes studied three are situated in southern Finland and one in the north (Fig. 1). Lakes Pyhäjärvi, Pääjärvi and Tuusulanjärvi are natural whereas lake Lokka is an artificial reservoir. Some basic information on the lakes is given in Table 1.

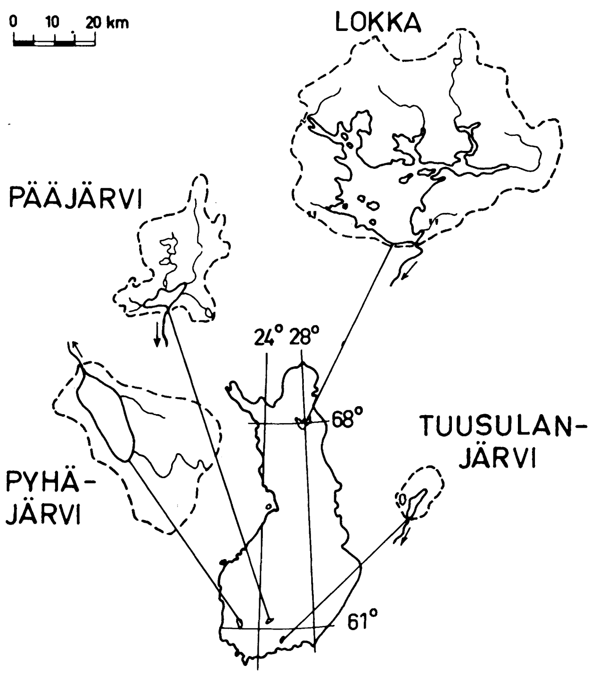

Fig.1. Four research lakes and their drainage areas.
(The scale is the same for all four).

Methods

Evaporation from the lakes studied was determined using the water budget method, the aerodynamical method and by direct measurement using GGI-3 000 pan mounted on a float. The results obtained have been compared with those from the nearest Class A pan station. The methods used here are well known, and only a brief review is presented in the form and to the extent used here.

The water budget method

The budget method requires measurement of changes in the lake level, precipitation, inflow and outflow. Evaporation is the unknown residual in Eq. (1) once the other entities have been measured

Table 1 - Description of Pyhäjärvi, Pääjärvi, Tuusulanjärvi and Lokka drainage basins.

	Pyhäjärvi	Pääjärvi	Tuusulanjärvi	Lokka
Drainage basin characteristics:				
Drainage area	615 km²	244 km²	92 km²	2380 km²
Lake percentage	25%	8%	8%	18%
Lake characteristics:				
Longitude	22°20′E	25°09′E	25°03′E	27°36′E
Latitude	61°00′N	61°06′N	60°26′N	67°55′N
Altitude	45 m	103 m	38 m	245 m
Area	154 km²	13 km²	6 km²	417 km²
Length	25,5 km	10 km	8 km	32 km
Width	9 km	3,5 km	2 km	26 km
Mean depth	5 m	14 m	3 m	5 m
Maximum depth	20 m	80 m	10 m	15 m
Air temperature:				
Mean whole year	+4.1°C	+3.3°C	+4.2°C	-1.1°C
Warmest month: July	+16.9°C	+16.7°C	+16.9°C	+13.9°C
Coldest month: February	-7.5°C	-8.9°C	-7.4°C	-14.1°C
Average frozen period	150 days	150 days	150 days	220 days
Mean precipitation in 1931-1960 (mm):				
Annual	630	660	700	580
June	48	52	52	55
July	71	72	76	70
August	81	81	77	72
September	63	63	67	54
October	66	65	70	52

$$I + P - O - E + S = \Delta W \quad (1)$$

I = inflow into the lake
P = amount of precipitation onto the lake surface
O = outflow from the lake
E = evaporation from the lake surface
ΔW = change in water level
S = net seepage

All these quantities are expressed in millimetres on the lake surface. This method has been applied to lakes Pyhäjärvi and Pääjärvi.

The bulk aerodynamical method

This method is based on Dalton's law, which has been suitably transformed. The partial pressure of the water vapour is measured at the water surface and at a certain elevation and the pressure difference multiplied by the wind speed. The equation is adapted to the units chosen using empirically determined constants. The air temperature and humidity, wind velocity and the surface water temperature have to be measured. Throughout this study we have used Eq. (2) (Shuliakovski 1969).

$$E = (0.15 + 0.108u_2)(e_0 - e_2) \quad (2)$$

E = evaporation from the lake surface in mm/d
u_2 = wind velocity in m/s at 2 m above the water surface
e_0 = the saturation vapour pressure in mb corresponding to the water surface temperature
e_2 = the water vapour pressure in mb at a height of 2 m above the water surface

All parameters needed were measured on a float carrying a self-contained meteorological station. These floats were triangular with sides 10 m × 10m × 8 m.

The floating GGI-3.000 evaporimeter

The float also carried a GGI-3.000 evaporation pan with a surface area of 3.000 cm² and a precipitation pan of the same size. Direct evaporation measurements were made twice a day on the float.

Correction was made for the difference between the water temperature of the lake and that of the pan by applying Eq. (3) (Kuznetsov 1970):

$$E = 0.88\, E_0 \frac{e_0 - e_2}{e'_0 - e_2} \qquad (3)$$

E = actual evaporation from the lake in mm/d

E_0 = evaporation from the GGI-3.000 pan in mm/d

e'_0 = saturation vapour pressure in mb corresponding to the water surface temperature in the GGI-3.000 pan

e_0 and e_2 are the same as in Eq. (2).

The lakes

Lake Pyhäjärvi

Pyhäjärvi is the largest lake basin in southwestern Finland, with an area of 154 km^2. The lake is more or less elliptical with the major axis running SE-NW. It is rather shallow with only a few islands. The shores are mostly wooded and rather flat. The water is clear and pure, as witnessed by the fact that fish reproduction per hectare is the highest in Finland. The lake is oligotrophic.

The evaporation from Pyhäjärvi was determined by the water budget and the aerodynamical method. The floating GGI-3.000 pan proved impractical when the water turned choppy due to high winds. Even so, it was possible to register the quantities needed for the aerodynamical method on the float.

The water level was registered using four limnigraphs, two situated close to each end of the nodal line of the principal lengthwise oscillation of the lake.

About 60 per cent of the inflow was measured directly using measuring weirs and the corresponding rating curves. The remaining part was evaluated by comparison and checked by single measurements. The outflow was determined by applying the rating curve to the limnigraph readings at the outflow point.

Precipitation onto the lake was determined from the rainfall measured with six gauges placed around the lake and one on an island close to the middle of the lake. Ground water levels were observed at different places close to the bank. Pressure differences indicated a small ground water seepage into the lake in some locations. No seepage from the lake basin was observed.

Lake Pääjärvi

This lake is situated about 100 km north of the south coast, close to the water divide between the lake district of central Finland and the coastal region. Compared with its area this lake is exceptionally deep in Finnish terms; the deepest place is about 80 m deep. The lake is somewhat elongated from west to east. About 40 per cent of the shore-line is steep and wooded. The water is clear and pure and the lake is oligotrophic.

The water budget, the aerodynamical and floating GGI-pan methods were used to determine evaporation.

More than 80 per cent of the inflow was measured using measuring weirs and the corresponding rating curves; the outflow was also measured in this way. The lake level was measured using three special volumetric instruments rendering water stages with an accuracy of 0.5 mm. Additionally, a single limnigraph was used to register the lake level.

Precipitation onto the lake was determined by means of four rain gauges placed around the lake and one on an island in the middle of the lake.

The floating GGI-3.000 installation was anchored close to the middle of the lake.

Lake Tuusulanjärvi

Tuusulanjärvi is situated in southern Finland, about 30 km north of the capital, Helsinki. The lake is rather long and narrow, running SW-NE. The banks are mostly flat and treeless, and largely cultivated. Because of a heavy nutrient load due to agriculture and the surrounding densely-populated area the lake is extremely eutrophic, and in this respect differs drastically from the other lakes.

Evaporation was measured using the aerodynamical method and the floating GGI-3.000 pan.

Lake Lokka

This artificial lake is situated in northern Finland, in the headwater region of the Kemijoki river. Its drainage area extends all the way to the divide between drainage to the Arctic Ocean and the Baltic Sea. The lake has an area of 417 km^2 when filled to its upper limit, making it the largest in this study. Its shape is more or less square with many fiordlike bays giving it an irregular appearance. Compared with its size, the lake is extremely shallow, with a mean depth close to 5 m only. The banks are wooded and mostly flat. The water contains a high level of humic substances, which give the lake its typical dark brown colour. The lake is dystrophic.

The climate in the region of lake Lokka is quite different from that of the other lakes studied. The period of open water averages only 140 days.

Evaporation was determined using the aerodynamical method and with the floating GGI-3.000 pan.

To facilitate observations the float was anchored about one kilometre from the southern shore. The wind velocity was also registered on an island in the middle of the lake.

Results and Conclusions

The evaporation values obtained for the period June-October with the different methods are presented in Table 2; the results are for each of the years 1971 to 1974 for each of the lakes studied. The results demonstrate quite well how lakes of different depths warm up differently: The water in the shallow lakes, Pyhäjärvi

Table 2 – Evaporation from the research lakes during June-October 1971 to 1974.

Lake	Year	Method	June	July	Aug	Sept	Oct	June-Oct
1. Pyhäjärvi	1971	Equation (2)	140	155	128	81	49	553
	1972	Water balance	58	128	115	59	47	407
		Equation (2)	79	111	104	50	24	368
	1973	Water balance	98	133	113	61	38	443
		Equation (2)	94	142	107	53	23	419
2. Pääjärvi	1971	Water balance	40	103	100	76	73	392
		Equation (2)	70	132	117	79	72	470
		GGI-3.000	111	138	118	82	67	516
	1972	Water balance	60	151	165	79	64	520
		Equation (2)	73	171	115	82	66	507
		GGI-3.000	79	159	121	81	65	505
	1973	Water balance	61	143	104	53	61	422
		Equation (2)	99	145	127	73	52	496
		GGI-3.000	98	163	118	58	40	477
	1974	Equation (2)	84	87	83	64		
		GGI-3.000	90	83	80	58		
3. Tuusulan-järvi	1973	Equation (2)	163	162	131	57	21	534
		GGI-3.000	149	150	113	55	26	493
	1974	Equation (2)	125	103	102	70	38	438
		GGI-3.000	108	85	89	52	35	369
4. Lokka	1972	Equation (2)	37	109	108	58		312
	1973	Equation (2)	40	123	67	45		275
		GGI-3.000	42	106	56	68		272
	1974	Equation (2)		71	89	61		
		GGI-3.000		72	62	41		

and Tuusulanjärvi, warmed up more rapidly and evaporated more than the deep lake. On the other hand heat stored in the deep Pääjärvi keeps evaporation going in the autumn. The results also show how different geographical conditions make the artificial lake Lokka different from the other lakes.

Table 3 gives a comparison between the evaporation observed on the lakes and the nearest Class A pan stations. When the floating GGI-3.000 pan was used, it was taken as the standard. The aerodynamical method was chosen as the standard for lake Pyhäjärvi. A GGI-3.000 pan set into the ground was also used at lake Pääjärvi.

All the Class A pan stations were land stations and measurements followed accepted procedures (WMO, 1966).

Of the stations in Table 3 Säkylä, Rokkila and Vuotso lie less than 1 km from the respective lakes. The distances from the other stations to the comparison lakes varies between 10 and 60 km. Mietoinen and Tikkurila stations lie about 10 km from the coast. At Rokkila the floating GGI-3.000 pan was compared not only with the Class A pan but also with a GGI-3.000 pan set into the ground up to its rim.

Table 3 shows that there is a considerable variation in the Class A pan coefficients between different months, a fact already known. In some cases the results are favourable for the whole period June-September.

There is too little observational data to allow any reliable conclusions to be drawn. The water budget method seems to be the least reliable at present. During the period of open water in 1974 there was too much rain to permit the determination of the inflow with sufficient accuracy.

The monthly evaporation values from the water budget method for the other years correlated with those obtained with the bulk aerodynamical method with a coefficient of 0.86 and with those measured with GGI-3.000 pans with a coefficient of 0.75.

The bulk aerodynamical method and the GGI-3.000 pan measurements gave results that were in good agreement: For the whole set of monthly evaporation values the correlation coefficient was 0.94; for the Pääjärvi data the correlation coefficient was 0.93, for Tuusulanjärvi 0.99 and for Lokka 0.80.

Table 3 – Monthly pan coefficients for the Class A pans according to the results from the research lakes: 1-3 Pyhäjärvi, 4-6 Pääjärvi, 7-8 Tuusulanjärvi, 9-10 Lokka.

No	Class A station	Method	Year	June	July	Aug	Sept	June-sept
1.	Mietoinen	Eq. (2)	1971	1.01	1.18	1.38	2.01	1.25
		,,	1972	0.49	0.93	1.19	1.38	0.95
		,,	1973	0.68	0.99	1.01	1.38	0.93
2.	Jokioinen	Eq. (2)	1971	0.87	1.00	1.12	1.61	1.05
		,,	1972	0.47	0.73	1.12	1.24	0.76
		,,	1973	0.56	0.76	1.15	1.57	0.82
3.	Säkylä	Eq. (2)	1971	0.97	0.92	1.32	2.20	1.13
		,,	1972	0.66	0.98	1.16	1.30	0.95
		,,	1973	0.81	1.10	1.23	2.15	1.11
4.	Rokkila	Floating GGI-3000	1971	0.93	0.96	1.29	2.16	1.14
		,,	1972	0.56	1.04	1.58	1.88	1.07
		,,	1973	0.67	1.02	1.23	2.44	1.03
		,,	1974	0.70	1.13	1.00	1.68	0.98
5.	Rokkila	Floating GGI-3000/	1971	1.07	1.36	1.70	2.87	1.48
		GGI-3000 set into	1972	0.84	1.65	2.01	2.43	1.55
		the ground	1973	0.98	1.61	1.70	2.61	1.49
6.	Vestola	Floating GGI-3000	1971	0.93	0.98	1.35	2.29	1.17
		,,	1972	0.62	1.05	1.58	2.14	1.12
		,,	1973	0.66	0.78	1.31	1.91	0.91
		,,	1974	0.79	0.96	1.05	1.45	0.98
7.	Tikkurila	Floating GGI-3000	1973	0.88	0.74	0.93	1.44	0.88
		,,	1974	0.81	0.90	1.05	1.29	0.95
8.	Vihti	Floating GGI-3000	1973	0.79	0.66	1.21	2.49	0.88
		,,	1974	0.93	1.11	1.36	1.54	1.15
9.	Vuotso	Eq. (2)	1972	0.32	0.73	1.46	4.00	0.89
		Floating GGI-3000	1973	0.35	0.66	0.95		
		,,	1974		0.74	1.51	2.73	
10.	Sodankylä	Eq. (2)	1972	0.30	0.70	1.21	2.59	0.80
		Floating GGI-3000	1973	0.33	0.54	0.68	3.15	0.63
		,,	1974		0.71	1.03	1.71	

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