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SEASONAL AND LONG-TERM VARIATION OF GROUNDWATER LEVELS IN SANDY AQUIFERS IN SOUTHERN FINLAND

by

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Abstract

Groundwater levels were observed in the aquifers at Hyrylä and Sipoo in southern Finland during the periods 1968–84 and 1952–73, respectively. At the areas, representing those used for water supply, most of the groundwater recharge occurs in spring. This increase was well explained by maximum water equivalent of snow and the initial groundwater depth as the only independent variables. The annual variation of groundwater level was best explained by the previous 12 month precipitation.

The role of lysimeter outflow and the groundwater level of the previous month was examined by a transfer function model. The monthly groundwater levels calculated with this model had a correlation coefficient of 0.954 with observed values.

Frequency analysis was used to study low groundwater levels and the duration of groundwater deficit periods was also analyzed. This was mainly aimed at answering practical questions of groundwater use.

Key words: variation of groundwater level, sandy aquifer, time series analysis, groundwater deficit.

1. *Introduction*

Even a short interruption of the availability of water can be very harmful in a municipal water supply. When a groundwater aquifer is used for water supply, groundwater level measurements and their evaluation are necessary in the estimation of the risk of possible interruptions. A good understanding of why, how much and how often groundwater levels fluctuate can help in the planning of the use of water supplies for periods of drought.

Statistical methods have been applied in the study of groundwater fluctuations by a number of authors. ERIKSSON (1970) used cross-spectrum analysis to study the dependence of groundwater levels on precipitation and river water level. KRIZ (1972) analyzed a 70-year weekly observation series of groundwater depths by several statistical methods. ZAPOROZEC (1984) evaluated the effects of precipitation on groundwater levels by regression methods. A large number of statistical groundwater studies has been recently reviewed by GANOULIS and MOREL-SEYTOUX (1985).

Only a few studies have been carried out in Finland on the long-term variation of groundwater levels (SOVERI 1985). This is partly explained by the fact that most observation series are still too short. The groundwater observation stations of the National Board of Waters were established in the middle of the 1970's. The eartlier observation network, consisting of about 40 stations, was started by the Roads and Waterways Administration in the early 1960's.

In this study, groundwater observations at Hyrylä and at Sipoo during the periods 1968–84 and 1952–73, respectively, were analyzed. Of particular interest were long-term variations in groundwater level and the effect of snowmelt and precipitation on these two aquifers.

2. *Description of the aquifers*

The Hyrylä and Sipoo groundwater stations are situated in southern Finland, at 60° 23′ N, 25° 02′ E and 60° 24′ N, 25° 11′ E, respectively. The distance between the stations is 8 kilometers (Fig. 1).

The Hyrylä experimental field station lies on a glacifluvial delta formation. This is the dominant form of accumulation of the layered sand materials. The size of this delta formation is about 3 km^2. The groundwater station is located in the middle on the groundwater divide. The mean height of the formation is about 60 m.a.s.l, the slope of the groundwater table is 1:2000. The mean groundwater depth in the period 1968–84 was 719 cm. The surrounding clay areas around the delta formation are at an elevation of 42...47 m.a.s.l. The texture of the soil at the Hyrylä station is shown in Table 1.

At Hyrylä the groundwater level was measured altogether at 15 points. The measurements formed a homogeneous set of observations: the correlation coefficient between the values at the measuring tube at the experimental station and

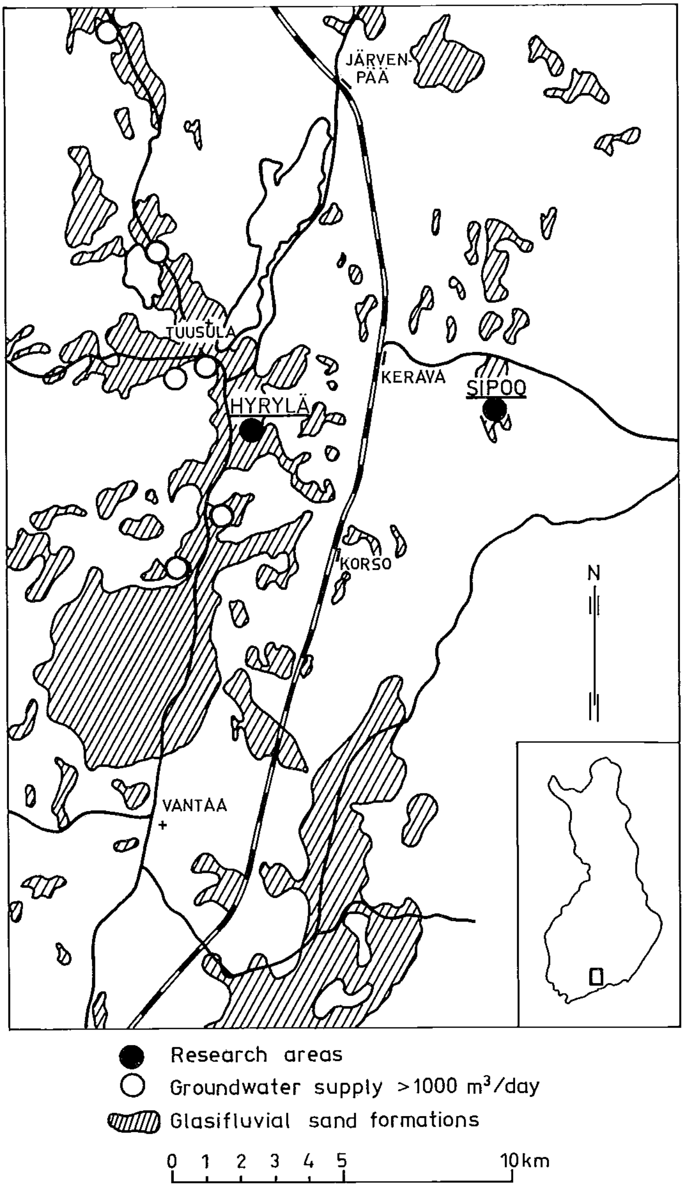

Fig. 1. The groundwater aquifers of Hyrylä and Sipoo.

Table 1. The grain size distribution of the soil at the experimental stations (in per cent).

	from surface to groundwater surface				in groundwater fluctuation zone			
	gravel	sand	fine sand	silt	gravel	sand	fine sand	silt
Hyrylä	3	56	36	5	0	65	35	0
Sipoo	1	52	42	5	3	54	39	4

the mean of all other observations was 0.998. Therefore the measurements in the measuring tube very well represent the whole aquifer.

The effective porosity in the fluctuation zone of the groundwater level was determined as the difference between the maximum water capacity and the field capacity. The maximum water capacity was measured in samples taken from the research area as well as in situ with the neutron method. The mean maximum water capacity was 36.5 per cent by volume. The value of the effective porosity was 26.5 per cent (LEMMELÄ 1970).

For a study of hysteresis phenomena porosity values were also measured during short periods with little evaporation and rapid formation of groundwater. The results of these measurements gave within the error limits of the measurements the same porosity values for increasing water content as gave the method with decreasing water content.

At Sipoo the station lies on the distal part of a 1 km^2 glacifluvial sand formation. The other accumulation forms here are eskers and sand fillings between the depressions on the bedrock. Coarse, layered materials cover at Sipoo map sheet about 5 per cent of the land area while the corresponding coverage at Hyrylä map sheet is over 35 per cent. The height of the Sipoo station is between 45...50 m.a.s.l., the groundwater level at the height 40...42 m.a.s.l., and the surrounding clay areas at 35...40 m.a.s.l. The mean daily water yield of groundwater at Sipoo sand area is 600 m^3, according to the pumping tests.

When comparing the aquifer of Hyrylä to that of Sipoo the following observations are made:

- Hyrylä aquifer is about 3 times wider than that of Sipoo and sand layers are also thicker at Hyrylä
- At Sipoo finer silt layers are on top at the measuring site and the soils are more graded than at Hyrylä which means that the effective porosity at Sipoo is smaller than at Hyrylä
- the groundwater surface lies about three meters deeper at Hyrylä than at Sipoo.

Generally Hyrylä aquifer represents the aquifers at the area used for municipal water supply with daily water yield over 1000 m^3 (Fig. 1) and Sipoo aquifer respectively the aquifers with daily water yield under 1000 m^3.

3. *General characteristics of the groundwater variation*

The cumulative frequency curves of groundwater depths at Hyrylä and Sipoo are shown in Fig. 2. The scales of the ordinate axis were selected so that the extreme depths at the two observation sites coincide.

The total amplitude of the variation of groundwater level was 137 cm at Hyrylä and 312 cm at Sipoo. The extreme depths (cm) were as follows:

	Min.	Date	Max.	Date
Hyrylä	644	Jan. 1975	781	Mar. 1977
Sipoo	244	Jun. 1967	556	Aug. 1960

Thus, all the extremes occurred outside the common observation period, 1968—73. During this period, the total amplitude of variations was 65 cm at Hyrylä and 174

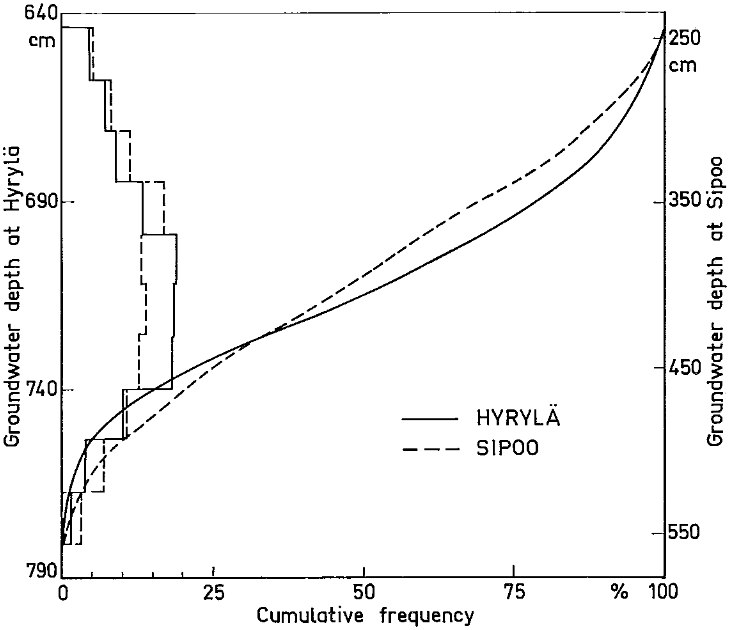

Fig. 2. The frequency curves of groundwater depths at Hyrylä and Sipoo for their total observation periods.

cm at Sipoo. The extremes during the common observation period occurred simultaneously, the maxima in May 1971 and the minima in March 1972.

At Sipoo the groundwater depths were distributed more evently over the total range of variation than at Hyrylä. When the total range was divided into ten equally spaced intervals, the four intervals with highest frequencies accounted for 54 % at Sipoo, whereas at Hyrylä the corresponding percentage was 68.

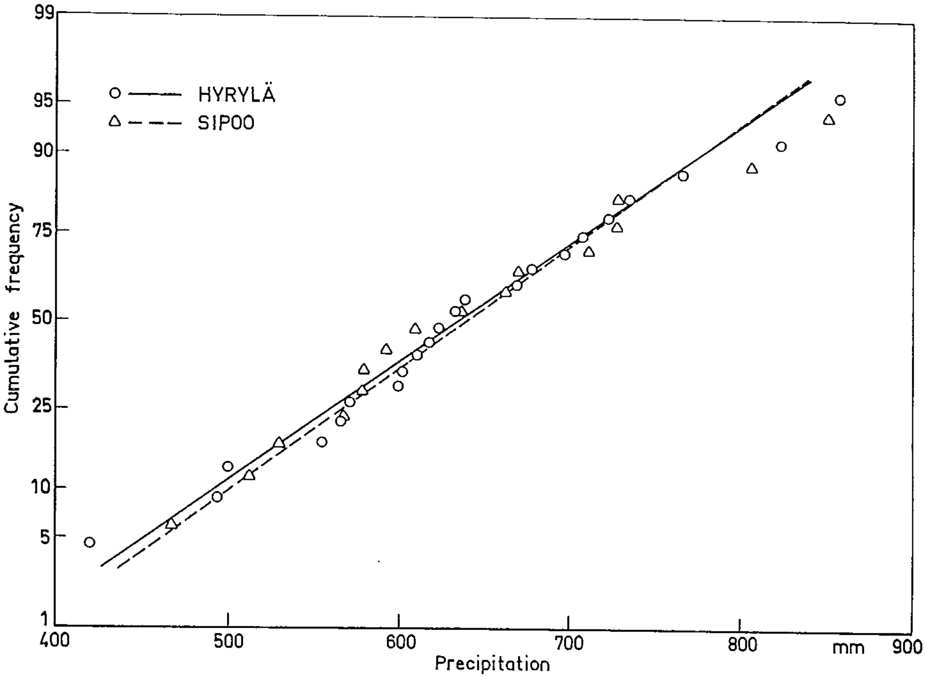

Fig. 3. The probability distributions of 12-monthly precipitation (November–October) at Sipoo in 1952–73 and at Hyrylä in 1968–84.

The twelve-monthly totals of precipitation were almost identically distributed throughout the whole observation periods at Sipoo and at Hyrylä (Fig. 3). The smallest twelve-monthly total at Hyrylä has a return period of about 35 years as compared to about 20 years at Sipoo. However the differences in the precipitation conditions are so small that the differences in the distributions of groundwater levels must mainly be due to the characteristics of the aquifers.

4. *Seasonal variations*

The monthly means of groundwater depths at Hyrylä and Sipoo during the common observation period (1968–73) are shown in Fig. 4.

The seasonal pattern of variation was almost identical at both of the sites. The minimum level occurred in March and the maximum in May. The difference between the extreme monthly means was 21 cm at Hyrylä and 40 cm at Sipoo.

The curves in Fig. 4 clearly depict the seasonal variation in groundwater recharge in southern Finland. Most of the recharge occurs during and after the snowmelt period. In summer and winter months the groundwater level decreases. In some years, recharge also occurs in autumn, but the mean monthly values do not clearly increase.

Unlike the groundwater recharge, the outflow from the lysimeter at a depth of 1.0 m was considerable in autumn. It amounted to 60 per cent of uncorrected precipitation total in September–November. According to the measurements the increase of soil moisture content, on the average 70 mm in the layer from soil surface to the depth of 3 m, was large enough to prevent or greatly reduce the percolation of precipitation to the groundwater storage (LEMMELÄ and TATTARI 1986).

In Fig. 4 the large difference between the December and January means is due to the fact that groundwater level was much lower in December 1973 than in

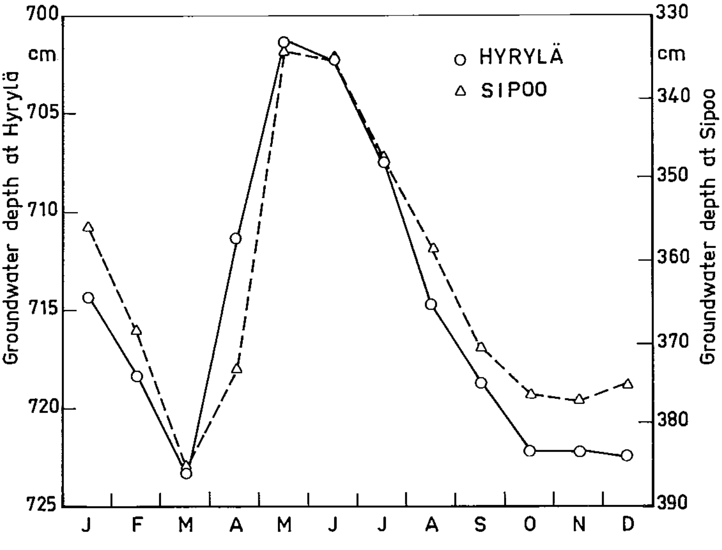

Fig. 4. The monthly means of groundwater depth at Hyrylä and at Sipoo during the common observation period, 1968–73.

January 1968. At Sipoo this led to a difference of 28 cm in these monthly means, at Hyrylä the corresponding value was 13 cm.

The regression equation between the monthly values of groundwater depth at Hyrylä (W_h) and Sipoo (W_s) was as follows:

$$W_h = 585 + 0.356\ W_s \tag{1}$$

The correlation coefficient of this model was 0.966 and it was significant at the level of 99.9 %. From the statistical point of view, this model would be good enough for the extension of the Hyrylä series backwards as far as the beginning of the observations at Sipoo.

5. *Long-term variation*

The annual means of groundwater level at Hyrylä and Sipoo during their observation periods are shown in Fig. 5. The correspondence of the annual variations between stations was good during the common observation period, 1968–73. This result was as anticipated from the high correlation between the monthly values.

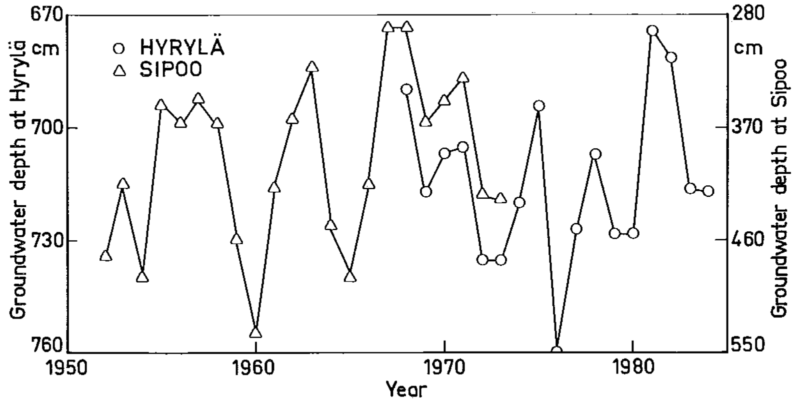

Fig. 5. The annual means of groundwater depth at Sipoo in 1952–73 and at Hyrylä in 1968–84.

The pattern of long-term variation of groundwater level can well be explained by variations in precipitation. The uncorrected twelve-monthly totals of precipitation from November to October were used rather than the annual values in order to include the total snowfall of the winter season in the precipitation total. When these twelve-monthly totals were used as independent variables, the following regression equations were obtained.

$$W_{hN} = 854 - 0.208\, P_h \tag{2a}$$

$$W_{sN} = 638 - 0.399\, P_s \tag{2b}$$

where

W_{hN} = groundwater depth at Hyrylä on Nov. 1st, cm

P_h = uncorrected precipitation at Hyrylä during the previous 12 month period, mm

W_{sN} and P_s are the corresponding values for Sipoo.

The correlation coefficient of Eq. (2a) was 0.89 and that of Eq. (2b) 0.58. The first model was significant at the level of 99.9 %, the second at 99 %.

A 100 mm increase in the twelve-monthly precipitation would therefore cause a 21 cm increase of groundwater level at Hyrylä and a 40 cm increase at Sipoo. The uncorrected precipitation sum of the preceeding 12-month period was also used as an independent variable, but it was not significant. Nor did the groundwater level on Nov. 1st in the previous year improve Eq. (2a). However, for Sipoo a better model was obtained with this variable, W'_{sN}:

$$W_{sN} = 419 - 0.311\, P_s + 0.436\, W'_{sN} \tag{3}$$

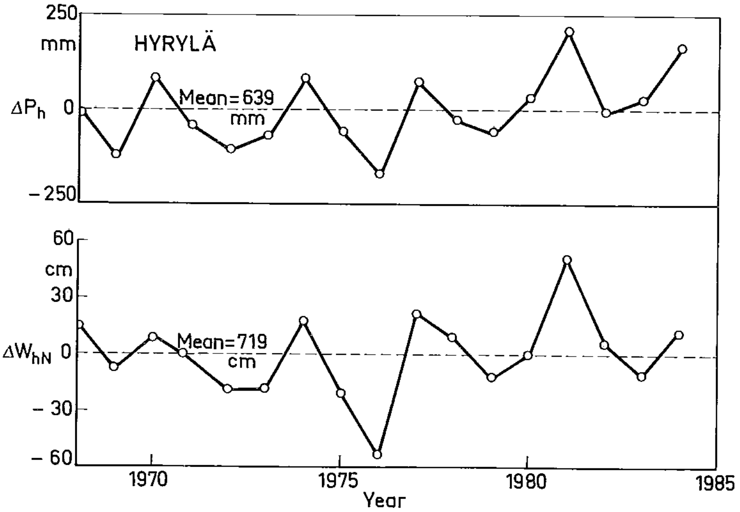

Fig. 6. The deviations of 12-monthly (Nov.–Oct.) precipitation from the mean of the whole period (= ΔP_h), and the corresponding deviations of groundwater depth on November 1st from their mean (= ΔW_{hN}). The data were taken from the observation site at Hyrylä.

The new independent variable was significant at the level of 95 %, but the correlation coefficient was only 0.005 better than that of Eq. (2b).

These results are similar with those obtained in the northwestern part of the USSR. In 16 observation sites the precipitation of the previous cold season explained on the average 61 % of the variation of the groundwater level. On the contrary in the southern part of the European USSR the effect of precipitation of three preceeding years to groundwater levels was found (SVIRINA and CHELIDZE 1979).

The relationship of Eq. (2a) can also be illustrated by the deviations of the variables from their average values in each year (Fig. 6). The groundwater level was above the average in almost all the years in which the precipitation was above the average.

The most significant increase of groundwater level in southern Finland was due to snowmelt and to precipitation during and after the snowmelt period

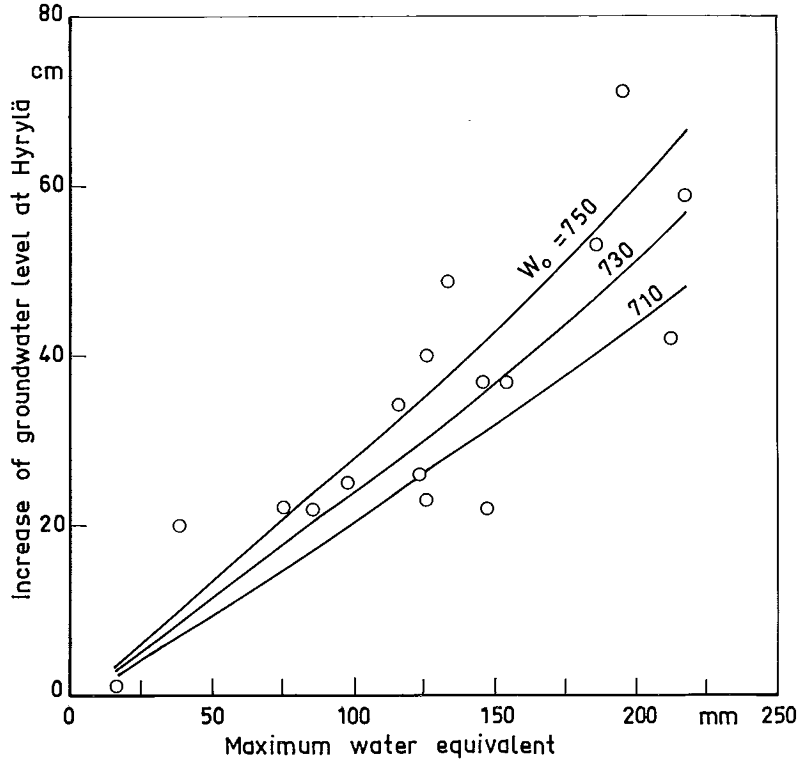

Fig. 7. The dependence of the springtime increase of groundwater level at Hyrylä on the maximum water equivalent of snow and on the initial groundwater depth (W_0, cm).

almost every year. These springtime increases were estimated from the observations at Hyrylä. The mean increase was 35 cm and the median 34 cm. The regression equation between these increases (ΔG, cm), the maximum water equivalent of snow ($L_{\max}$, mm) and the initial groundwater depth (W_0, cm) was as follows:

$$\ln \Delta G = 1.12 \ln L_{\max} + 5.54 \ln W_0 - 38.5 \tag{4}$$

The total correlation coefficient of this model was 0.93; with $L_{\max}$ as the only independent variable the correlation coefficient was 0.90. In Eq. (4) the former independent variable was significant at the level of 99.9 % and the latter at the level of 95 %. A 20 mm higher maximum water equivalent causes an increase of 5...6 cm in groundwater level, whereas the corresponding increase caused by a 20 cm higher initial groundwater level is 1...5 cm (Fig. 7).

6. *Some results of time series analysis*

The effect of monthly precipitation values on groundwater level is obviously different in different months. On the contrary, the relationship between the outflow from the lysimeter and the fluctuations of groundwater level may be stable throughout the year. This relationship was studied with a transfer function model (Box and Jenkins 1976). Monthly totals of lysimeter outflow at Hyrylä (Q_i) and monthly averages of groundwater depth at the same site (W_i) were used.

Fig. 8 shows the autocorrelation function of the variable W_i and the cross correlation between the variables W_i and Q_i. The autocorrelation function decreases very slowly as a function of time lag. The cross correlation function reaches a maximum with a time lag of one month.

The best transfer function model was found to be the following:

$$W_i = 0.985\, W_{i-1} - 0.123\, Q_{i-1} + 15.1 \tag{5}$$

Fig. 9 shows the observed monthly groundwater depths for years 1969–1983 together with those calculated with Eq. (5). The correlation coefficient between the observed and calculated mean monthly groundwater depths for these fifteen years was 0.954. The largest differences between measured and calculated values occur in spring due to the relatively large time step; a weekly or half-monthly forecast model would be more suitable in springtime.

A model analogous to Eq. (5) was also calculated separately for each month from June to December. These models were compared to models, where mean monthly groundwater depths were explained by cumulative precipitation and mean air temperature of the preceeding month (Table 2).

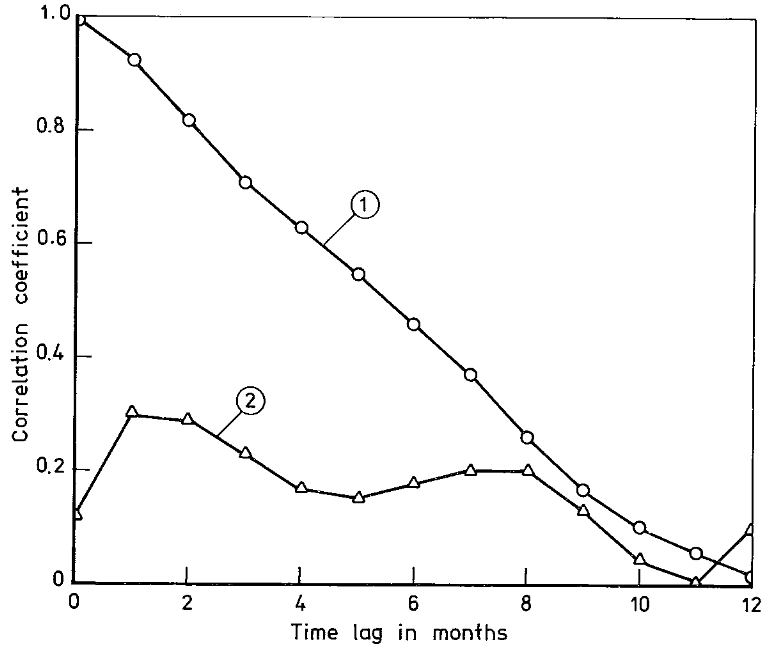

Fig. 8. The autocorrelation function of groundwater depth (1) and the cross correlation function of this variable with the monthly totals of lysimeter outflow (2). Observation site is Hyrylä with the data from 1969 to 1983.

Table 2. The results of regression analyses of mean monthly groundwater depths. The independent variables are mean monthly groundwater depth (W_{i-1}), cumulative precipitation (P_{i-1}), mean air temperature (T_{i-1}) and cumulative outflow from the lysimeter (Q_{i-1}), all for the preceeding month. R is the total correlation coefficient, S the standard error of estimate of the model. The significance levels are 99.9 % (★★★), 99 % (★★) and 95 % (★).

	With observations of P and T					With lysimeter observations			
	Significance of			R	S (cm)	Significance of		R	S (cm)
	W_{i-1}	P_{i-1}	T_{i-1}			W_{i-1}	Q_{i-1}		
June	★★★			0.972	6.9	★★★		0.969	7.0
July	★★★			0.977	6.1	★★★	★	0.981	5.3
August	★★★	★★		0.985	4.4	★★★	★	0.972	5.7
September	★★★	★★	★	0.986	3.9	★★★		0.968	5.8
October	★★★	★★		0.962	6.3	★★★		0.926	8.4
November	★★★	★★★		0.985	4.9	★★★	★★	0.978	5.7
December	★★★			0.973	8.2	★★★	★	0.977	7.3

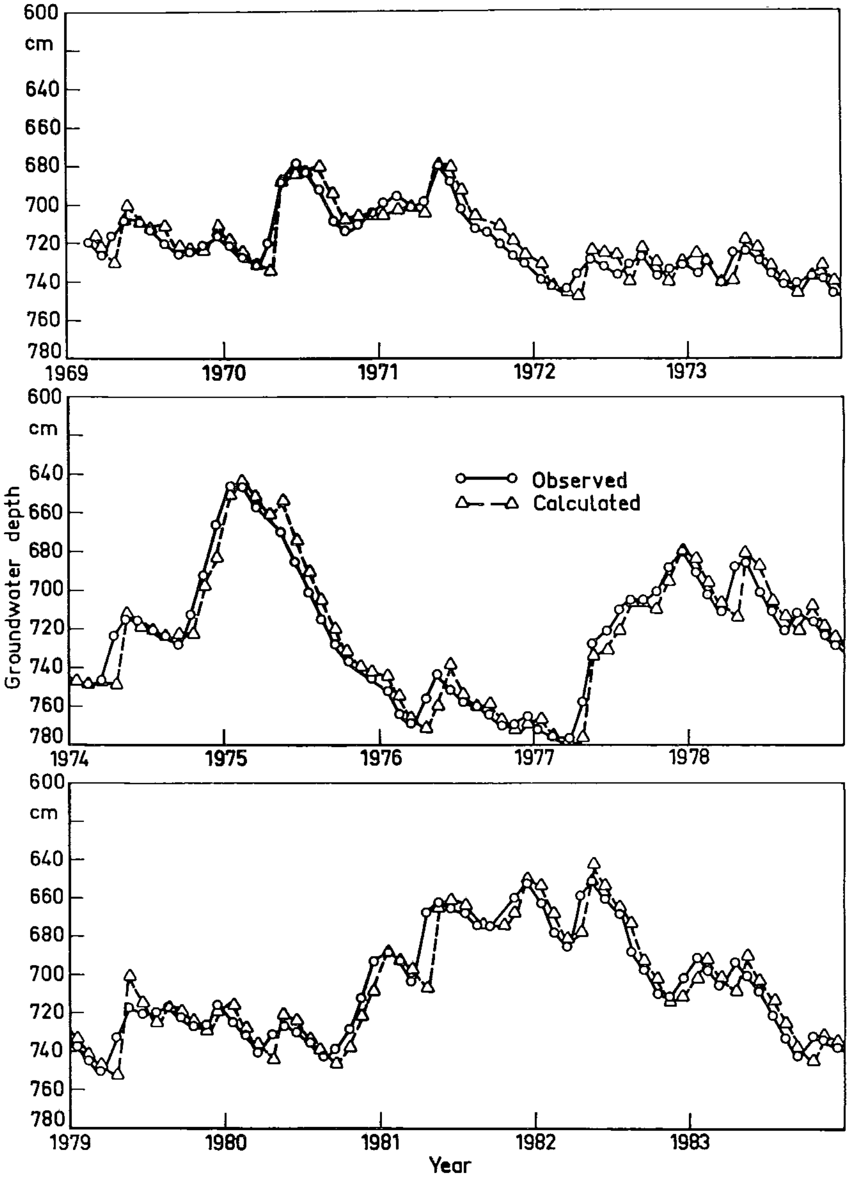

Fig. 9. Observed and calculated (with Eq. 5) monthly mean groundwater depths at Hyrylä from 1969 to 1983.

The latter model turned out to be better except for July and December. The cumulative precipitation of the preceeding month was significant from August to November at the level of 99...99.9 %. Mean air temperature was significant only in September. The lysimeter water yield was significant at the level of 95...99 % in four months, but in general it was not as good as the precipitation variable.

7. *Groundwater deficit*

One method for the study of low groundwater levels or groundwater deficit is a frequency analysis of annual minima. This analysis was carried out for both observation series (Fig. 10). The minimum levels do not fit very well with Gumbel's distribution, which may be a consequence of the interdependence of the consecutive values. However, it can be estimated from Fig. 10 that *e.g.* a well at Hyrylä running dry once in 5 years would run dry only once in 17 years, if it

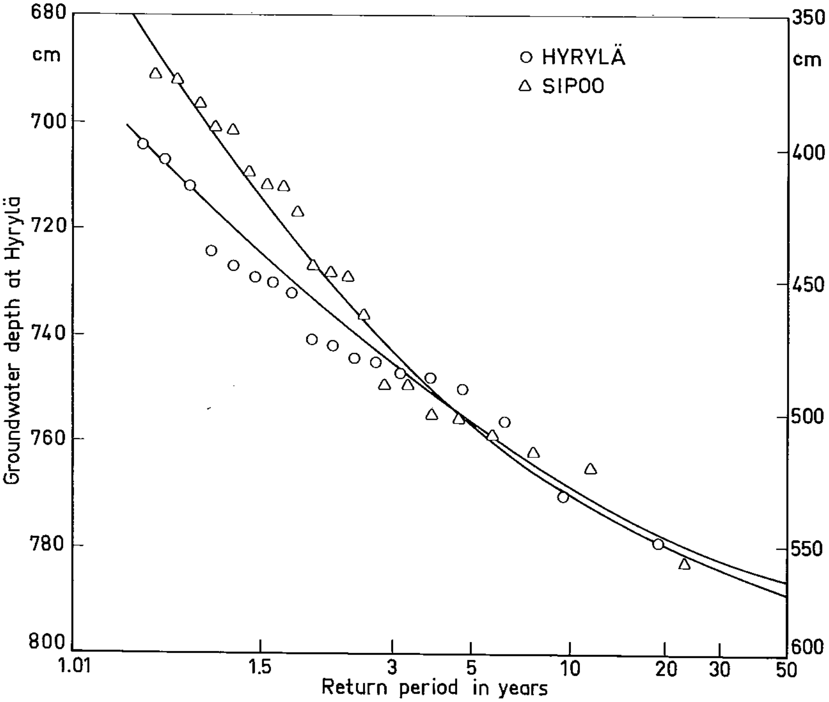

Fig. 10. The frequency analysis of minimum annual groundwater levels at Sipoo in 1952–73 and at Hyrylä in 1968–84.

were 20 cm deeper. This example is obviously valid only if the withdrawal of water does not influence the groundwater level.

The cumulative frequency curves of groundwater depths (Fig. 2) can also be used to study the occurrence of low groundwater levels. However, these curves do not provide any information on the durations of individual groundwater deficit periods. These periods were analyzed from the observations at Hyrylä, separately for groundwater depths from 700 cm to 780 cm (with an interval of 10 cm).

Fig. 11 shows the mean and maximum durations of the deficit periods. For depths 700...740 cm, the number of deficits varied between 14 and 16. For greater depths is was considerably lower. The maximum duration of deficit for the depths 700...720 cm occurred in 1971–74 and for the greater depths in 1975–77.

The durations of the groundwater deficits at Hyrylä with different probabilities and for different groundwater depths were analyzed on normal probability paper.

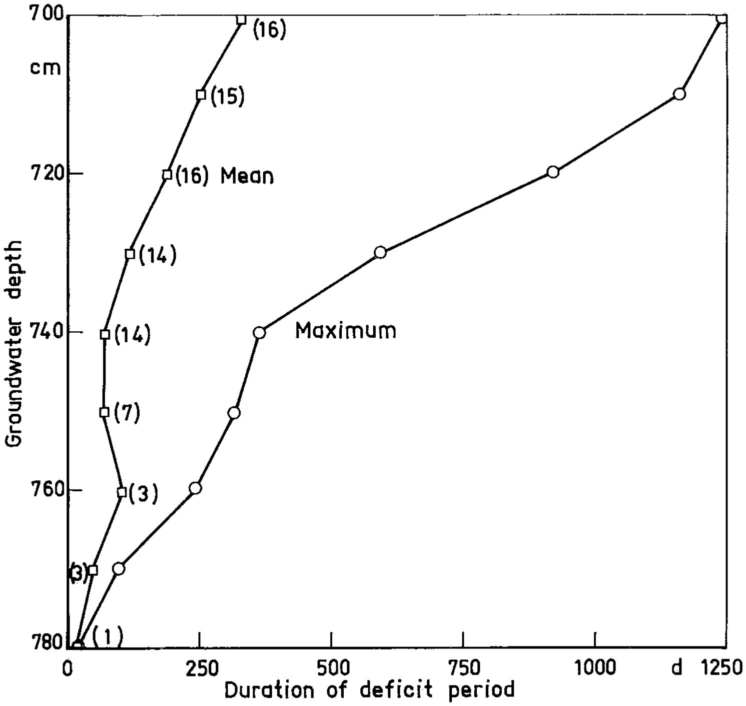

Fig. 11. The mean and maximum lengths of the periods during which groundwater remained below certain levels at Hyrylä in 1968–84. The numbers in parenthesis refer to the number of deficit periods for each depth.

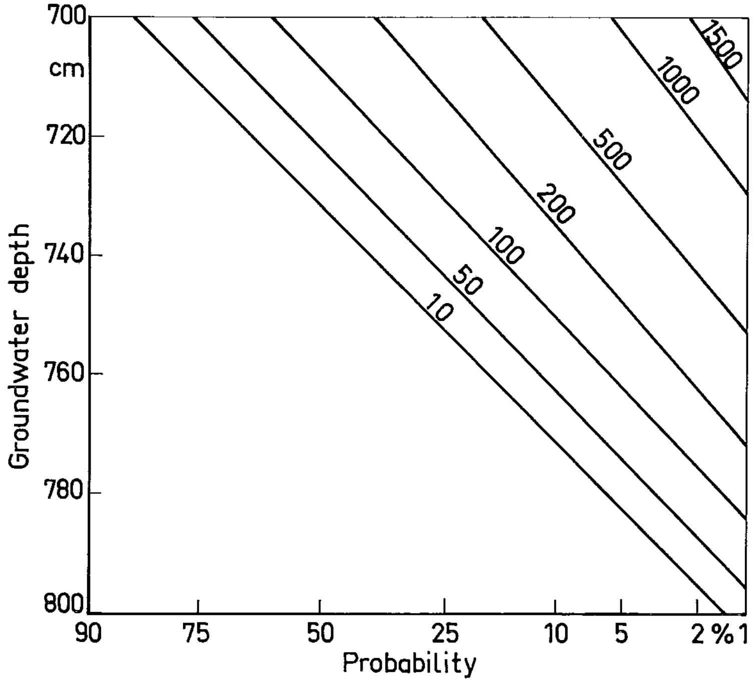

Fig. 12. The durations (in days) of the groundwater deficits with different probabilities and for different groundwater depths at Hyrylä in 1968–84.

The results are presented in Fig. 12. For example, a one hundred day duration had a probability of 60 % for the depth of 700 cm, but only 6 % for the depth of 760 cm. If the probability of a hundred day deficit should be smaller than 1 per cent, a well with a depth of 783 cm or more would be needed.

8. *Conclusions*

The following conclusions can be drawn concerning seasonal and long-term variations of groundwater levels in sandy aquifers in southern Finland.

(1) Analysis of the two observation series, Hyrylä (1968–84) and Sipoo (1952–73), revealed an almost identical pattern of seasonal variation at both sites. However, the amplitude of variation was 2.3 times greater at Sipoo than at Hyrylä. This was mainly due to the facts that the size of Sipoo aquifer is only about one third of that of Hyrylä and the soils at Sipoo are more graded than at Hyrylä.

(2) The annual variations of groundwater level were best explained by the previous 12-month precipitation. According to regression relationships, a 100 mm increase in the 12-month precipitation would cause a 21 cm increase of groundwater level at Hyrylä and a 40 cm increase at Sipoo.

(3) At the aquifers most of the recharge occurs in spring. At Hyrylä this springtime increase of groundwater level was explained by the maximum water equivalent at the level of 99.9 % and by the initial groundwater depth at the level of 95 %. Although percolation plays a remarkable role also during autumn, the increase in soil moisture content, being on the average 70 mm from September to November, is large enough to prevent or greatly reduce the rise of the groundwater level.

(4) A transfer function model was used on monthly basis to study the effect of lysimeter outflow values on groundwater level. The correlation coefficient between observed and calculated mean monthly groundwater depths for the fifteen years was 0.954. An analogous regression model was also calculated separately for each month from June to December using precipitation and air temperature of the previous month as independent variables. In general the precipitation variable was better than the lysimeter water yield variable.

(5) Frequency analysis was used to study low groundwater levels. It was mainly aimed at answering practical questions of groundwater use. For example at Hyrylä, a well running dry once in five years would run dry only about once in fifty years if it were excavated 30 cm deeper. The duration of groundwater deficit periods at Hyrylä was also analyzed. A hundred day duration had a probability of 60 % for the depth of 700 cm, 6 % for the depth of 760 cm and only 1 % for the depth exceeding 780 cm.

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