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The Climate Change and Groundwater Regimes in Finland

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Abstract
The boreal climate zone, which Finland is situated in, causes four seasons: cold winters, cool springs, short summers, and wet autumns. The aquifers are shallow and residence times are from a few months to a few years. The groundwater levels increase or decrease according to season changes. The annual cycle depends on the groundwater regime. The analysis of the years 1974-2007 indicates that the groundwater regimes have slightly moved northwards. The climate change scenarios for temperature and precipitation together with the Watershed Simulation and Forecast-ing System project that this trend will continue. The prognosis is, that winters will shorten, and the summer periods will become longer and warmer. Dryness will increase during summertime while wetness will increase during wintertime. It is possible that in the future there will only be two sea-sons: wet winters and dry summers.

Keywords
Climate change; groundwater; groundwater levels; groundwater regimes; scenarios.

I. Introduction

Finland is situated in the boreal climate zone. Some areas in the northern part have a polar climate. The main factor influencing Finland's climate is the geographical position between the 60^{th} and 70^{th} northern parallels in the Eurasian continent's coastal zone. This allows characteristics of both a maritime and continental climate, depending on the direction of air flow. The mean temperature in Finland is several degrees higher than that of some other areas in this latitude. The temperature is raised by the Baltic Sea, inland waters and above all by airflows from the Atlantic, which are warmed by the Gulf Stream.

The annual precipitation is between 550… 700 mm in Southern Finland and 450… 600 mm in Northern Finland. The mean annual temperature is between +5… -2^{o}C. The coldest month varies from - 3^{o} C in the southernmost parts of the archipelago to -15^{o}C in the northern parts of Finland. During the warmest month the mean temperatures in Southern and Central Finland varies between +15… +17^{o} C and in Northern Finland between +11… +15^{o} C. (Drebs et al., 2002).

Groundwater recharge is low during the winter months because the upper parts of the soil are frozen and also because precipitation as snow efficiently prevents infiltration. Therefore the main recharge period occurs in connection with the spring thaw. In the coastal areas another recharge period occurs in connection with the autumn precipitation. During summer, the evapotranspiration is generally so high in most areas, that groundwater recharge only occurs sporadically.

The Precambrian crystalline basement of the Baltic shield forms the bedrock, which is overlaid mostly by Quaternary deposits. The most widespread Quaternary sediments are usually composed of till overlying the crystalline bedrock. The average thickness of the Quaternary sediment is less than 7 metres. The till is normally composed of sand and silt. Glacio-fluvial sediments like eskers and associated formations, deltas and outwash plains, as well as the large terminal moraines, the Salpausselkä Ridges, are the formations where groundwater recharge is high.

The flow of groundwater through shallow Quaternary sediments is generally rapid, with residence times from a few months to a few years depending on the size of the aquifer. This research discusses the impact on smaller aquifers.

There are 54 groundwater stations in Finland that have been functioning since 1974 in a nation – wide program to monitor and evaluate the changes in groundwater levels. Approximately 40 of the stations are smaller aquifers. The groundwater stations are situated in variable climate conditions and soil types where human impact has initially been subtle. The monitoring of groundwater levels at the stations is done by measuring the water level in 10 observation wells twice a month.

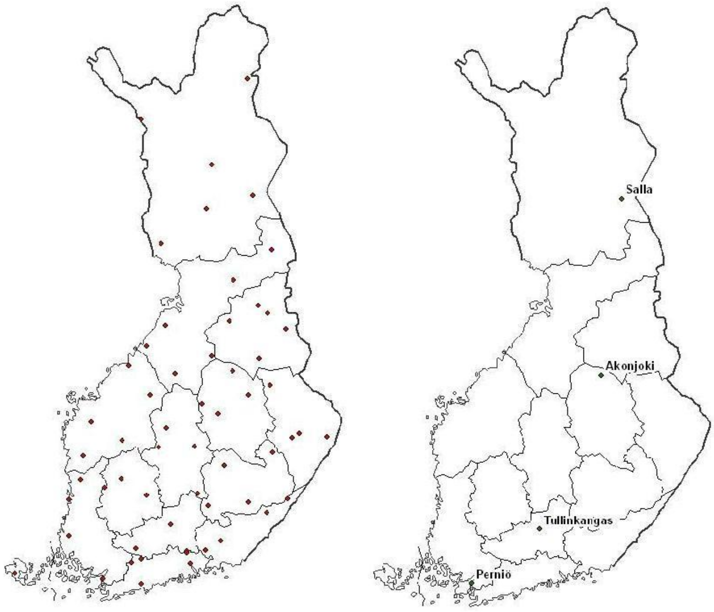


Fig. 1. a) The groundwater station network in Finland.
b) The stations referred to in this study.

II. Methods

This study was carried out by examining the data of groundwater level changes during the past three decades. It is a simple analysis based on two different factors: a) the variation of groundwater levels in Finland during the period between 1974 and 2007, b) the temperature and precipitation scenarios within the Watershed Simulation and Forecasting System (WSFS- described in detail below) which shows simulations of the years 2010-39, 2040-69 and 2070-99 (Veijalainen, in press).

Four time periods of data were selected: 1974-1979, 1980-1989, 1990-99 and 2000-07. Changes in groundwater level were analyzed using a total number of four stations with a record length of 34 years of data. Using the WSFS-model and climate scenarios simulations of changes in groundwater levels were made for the reference period of 1971-2000 and for the years 2010-39, 2040-69 and 2070-99.

The WSFS is widely used in Finland for real time hydrological simulation and forecasting (Vehviläinen et al., 2005). The development of the WSFS is based on a rainfall-runoff model with the same basic structure as the HBV-model widely used in Scandinavia. The WSFS covers the en-tire land area of Finland including cross-boundary watersheds, in total 390 000km^2. The distribution of the model is based on the third level watershed division with approximately 60 – 100 km^2 sub-basins. The main meteorological inputs are precipitation and temperature. The groundwater level simulation within the WSFS was developed by the Finnish Environment Institute. The groundwater simulation is included into the operational version of the WSFS. Groundwater level simulations and short term forecasts (10 days forecast based on meteorological forecasts received from ECMWF/FMI and the groundwater forecast is based on 52 forecast runs, which are based on daily weather series from 1961 to 2006) are now available for all groundwater observation stations (www.environment.fi/waterforecast). Future scenarios for changes in groundwater levels were obtained from the WSFS and a preliminary study on long term climate change effects on groundwater levels was made for four groundwater stations.

The Finnish hydro-geologic regimes were characterized by groundwater availability in our humid and cold climate. The left map in Fig 2 shows the mean seasonal groundwater level variation pat-tern in Finland based on monthly mean levels from groundwater stations from 1974-1982 (Soveri, 1985). The map on the right is based on the years 1974-2000 (Mäkinen, 2003).

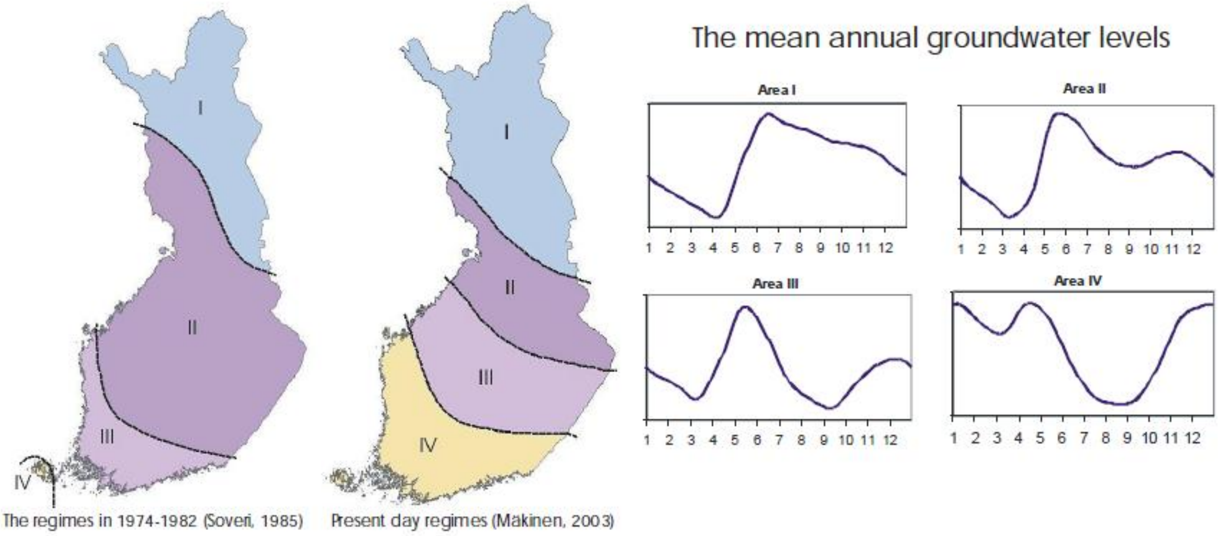


Fig. 2. **The groundwater regimes and the mean annual groundwater levels in Finland.**

A few observation stations were selected to represent the general behavior of groundwater in different parts of Finland. The objective is to describe the main features of groundwater level changes during the past decades under natural conditions and under the effect of possible climate warming.

The development of climate and atmospheric CO_2 concentration scenarios are based on the Inter-governmental Panel on Climate Changes (IPCC) Special Report on Emission Scenarios (SRES) (Nakienovi et al., 2000). Accounting for uncertainties in the climate sensitivity and using all 35 scenarios gives a large range for the global mean temperature will rise during the 21^{st} century by 1-3º C (Jylhä et al., 2004).

The climate scenarios were provided by The Finnish Meteorological Institutes (FMI) and are based on several global models and emission scenarios. In this investigation the main emissions scenario is SRES scenario A1B, where emission of carbon dioxide and other greenhouse gases are intermediate compared with other emission scenarios. One simulation was done with A2 emission scenario, which assumes high emissions and one with B1, which assumes low emissions. Scenarios from three global climate models and one scenario based on an average from the results of 19 climate models (the so called mean scenario) were used together with A1B emission scenario and the aver-age of 19 models was also simulated with A2 and B1 emission scenarios. The climate models used were ECHAM5/MPI-OM, UKMO-HadCM3 and CCSM3 (by NCAR) (IPCC, 2007). The number of scenarios in this preliminary study was altogether six.

III. Results and discussion

There are different patterns for annual fluctuations in groundwater levels. The variation is con-trolled by the recharge-discharge mechanism, which is highly dependent on the climate, but the local soil-and rock foundations also have an effect. The patterns can be used as models for predicting groundwater availability during different times of the year. The pattern curves are generalized and they reflect the average climatic conditions of the area.

In the coastal areas of Southern Finland the groundwater level reaches its maximum in early spring. Much of the precipitation during the winter is rain compiled with some soil frost. During summer-time, the groundwater level decreases to its minimum in late summer because of evaporation. High precipitation and decreased evaporation in the autumn raises the groundwater level back again. A large part of Finland belongs to the region that has two annual maxima and two minima changes in groundwater levels. One minimum occurs in late winter and the other one in late summer. One of the maximum peaks occurs after the snow melts in the spring and the other one in autumn after times of high precipitation. In Northern Finland the groundwater level has one annual minimum just before the snow cover melts and one maximum after the melting of snow. (Kirkhusmo, 1988).

The first examined site, Perniö groundwater station, is situated in Southwestern Finland. The winter period of the year is short because spring is early. The summer period is long in general. The groundwater level decreases to its minimum during summertime. The past ten years have had many dry summers (1999, 2002, 2003 and 2006), which has caused the groundwater level to sink significantly. There were also some dry periods in 1994, 1997, and in 2000. The exceptionally severe drought of 2002 and 2003 can be seen clearly in Fig. 3. The monthly means of the years 83-89, 90-99, and 2000-07 are presented in Fig. 4. It seems that during the period of 1983-2007, the ground-water levels have decreased slightly, the duration of winter has reduced and the summertime drought period has drawn out.

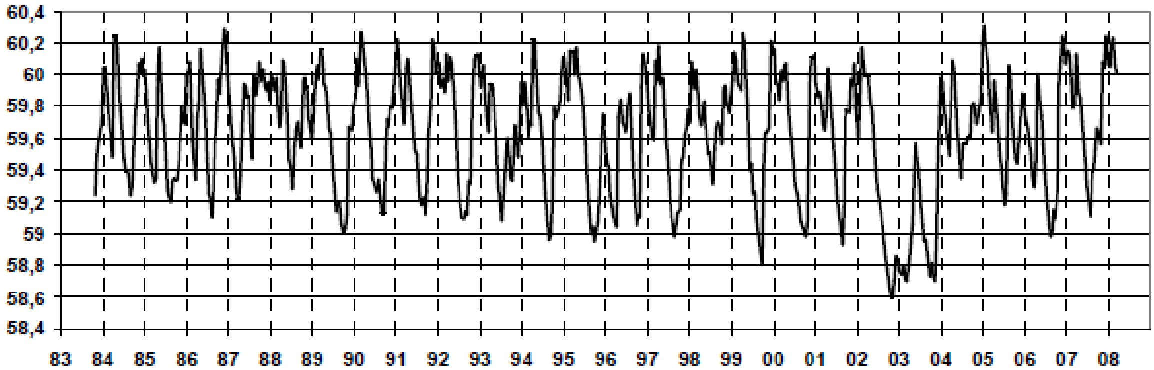


Fig. 3. Groundwater levels at Perniö groundwater station.

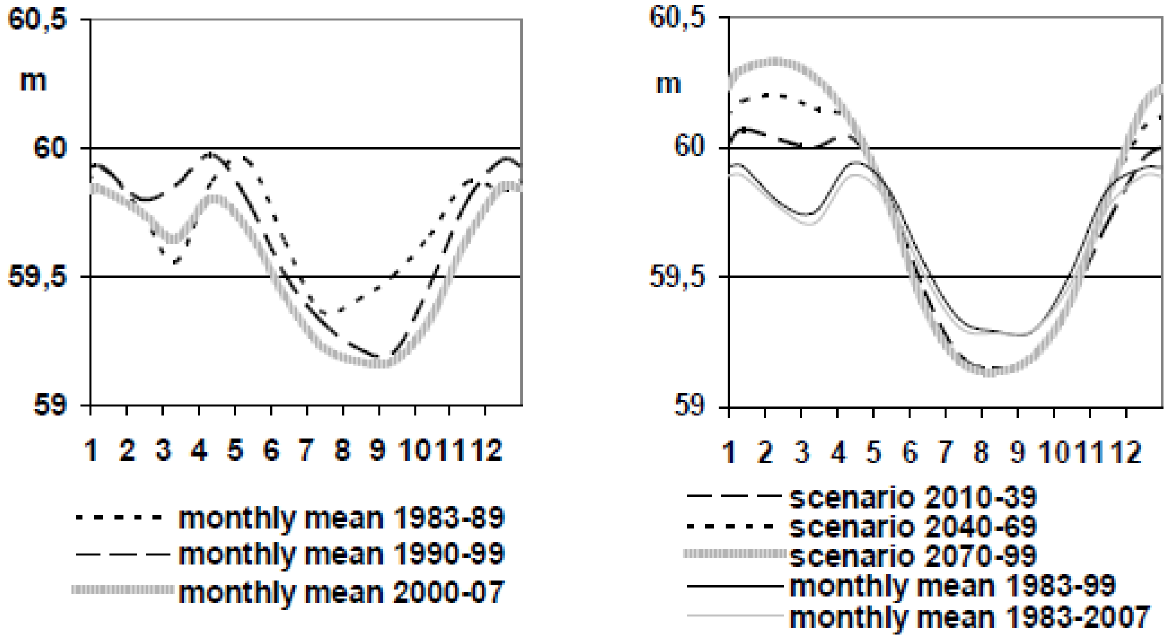


Fig. 4. Monthly means and scenarios (with the mean climate scenario) for Perniö groundwater station.

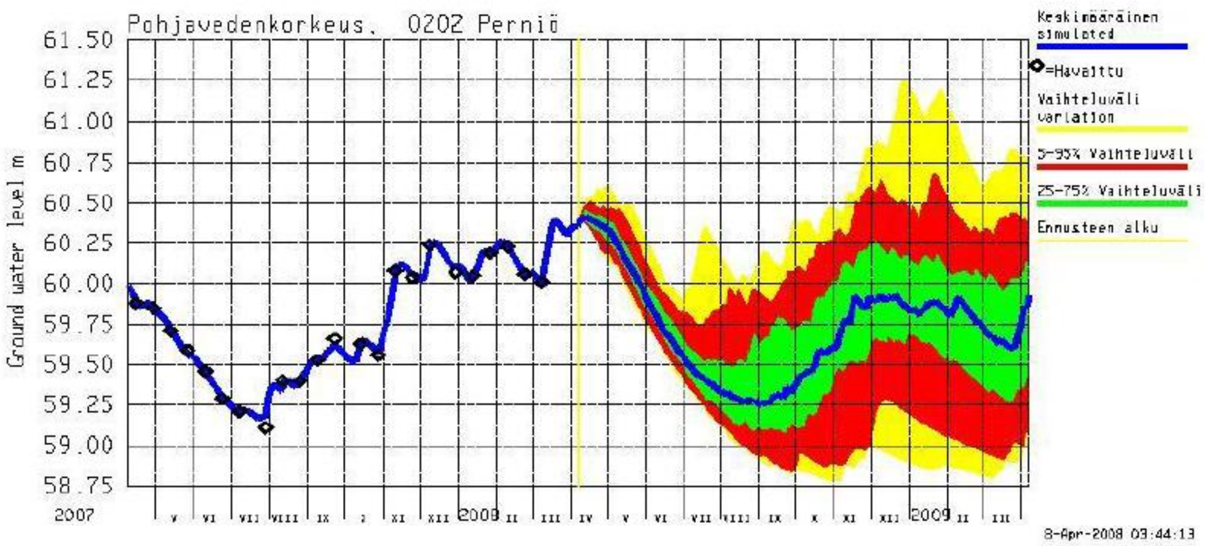


Fig. 5. The short term forecasts and the actual observations (o) for Perniö groundwater station.

The short term simulation and the actual observed groundwater levels for Perniö groundwater station are presented in Fig. 5. Three future scenarios (2010-2100 in Fig. 4) of the behavior of groundwater levels at Perniö groundwater station project that winters will moisten, and that the frost period after the long dry summers will shorten. Dryness will increase during summertime while wetness will increase during wintertime.

The second examined site, Tullinkangas groundwater station, is situated in Southern Finland. It belongs to same groundwater regime as Perniö groundwater station. The groundwater level changes have been analyzed from the period 1971-2007. The summers 1995, 1997, 1999, 2002, 2003, and 2006 were dry. There were also some dry periods in 1975-76. The exceptionally severe drought of 2002 and 2003 as well as the drought in 1976-77 can be seen in figure 6.

The simulated and observed monthly mean groundwater levels for Tullinkangas groundwater station are presented in Fig. 7. The monthly mean levels of groundwater have increased between the period of 1980- 2007. The drought period in 2002-2003, causes an erroneous result (too low) of the monthly means from January to April for the period 2000-07 (Fig.7). The spring maximum will remain low, but the summertime levels will decrease. The simulated scenarios predict the same trend to continue in 2010-2099. According to the scenarios, winters will moisten, and the frost period after the long dry summers will shorten. Dryness will increase during summertime while wetness will increase during wintertime. The evaporation of summertime and the prolonged growth period will eventually specify the future behavior of groundwater levels.

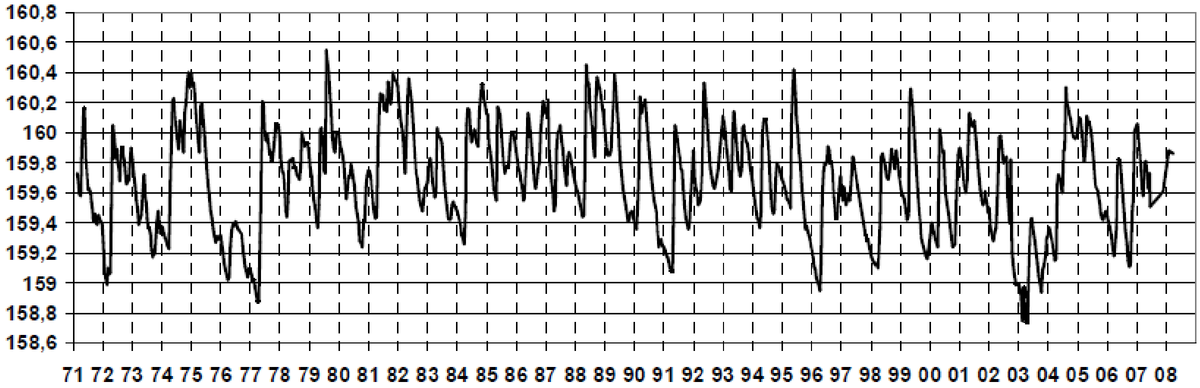


Fig. 6. Groundwater levels at Tullinkangas groundwater station.

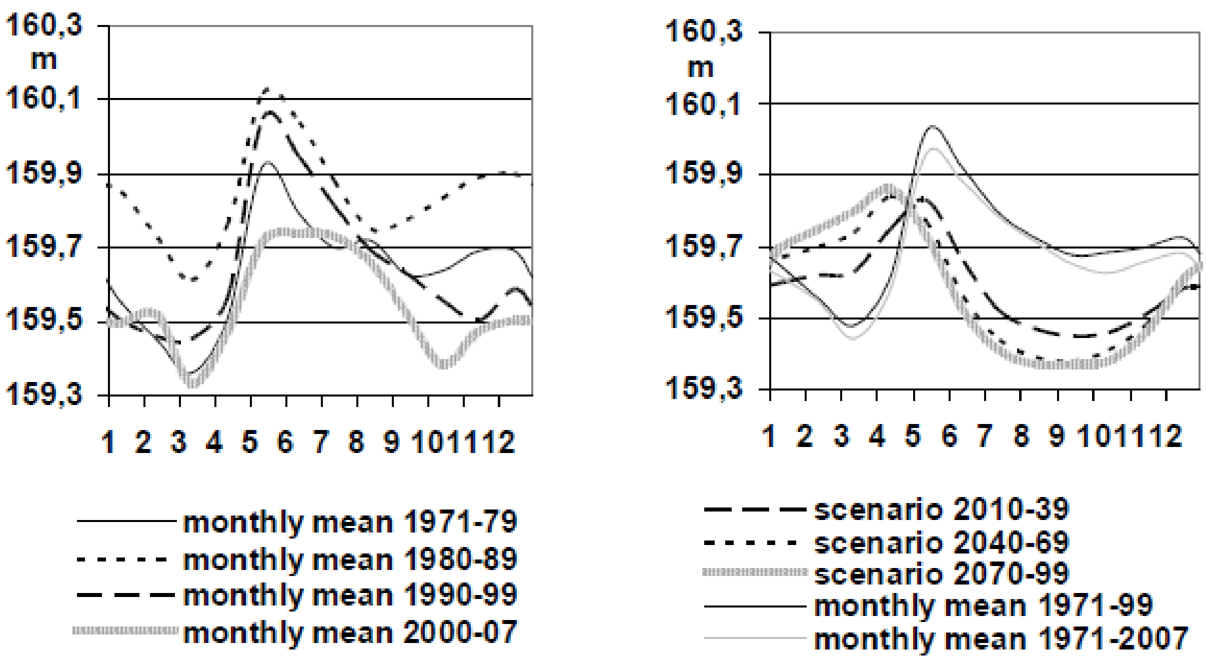


Fig. 7. Monthly means and scenarios (with the mean climate scenario) for Tullinkangas groundwater station.

The third example, Akonjoki groundwater station, is situated in Central Finland. The groundwater station belongs to the regime where groundwater levels have two annual maxima and two minima

(Fig. 2). One minimum occurs in late winter, just before the spring thaw, and the other minimum occurs in late summer. One maximum occurs after the spring thaw and the other one at the end of the year, due to the autumn precipitation. The summers of 2002 and 2006 were warm. The warm summer and autumn of 2002 led to decreased groundwater levels during the annual minimum of wintertime in 2003.The same trend can be seen in the monthly means from 2000-07. The scenarios for 2010-2099 predict that wintertime moisture will increase and summertime groundwater levels will decrease. According to climate change scenarios, the wintertime precipitation will increase in Central Finland. This causes the wintertime maximum to increase significantly, but it will not have a large effect on the summertime minimum.

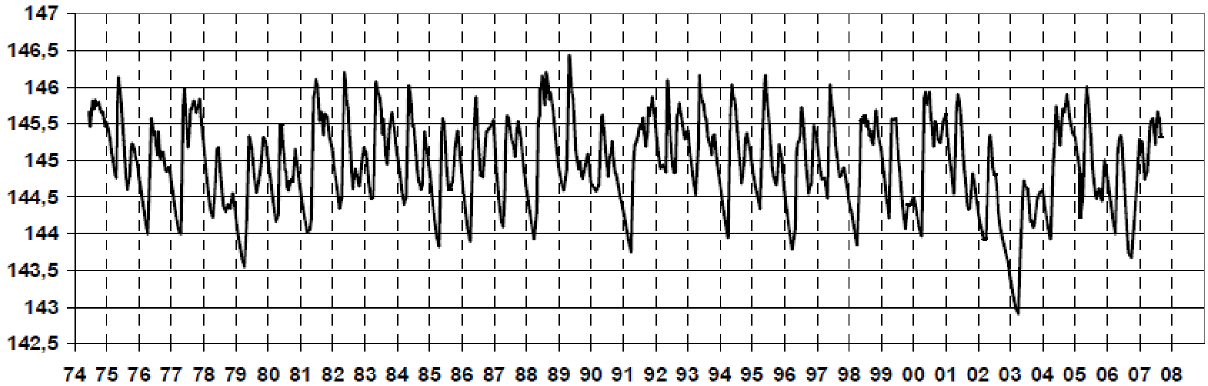


Fig. 8. Groundwater levels at Akonjoki groundwater station

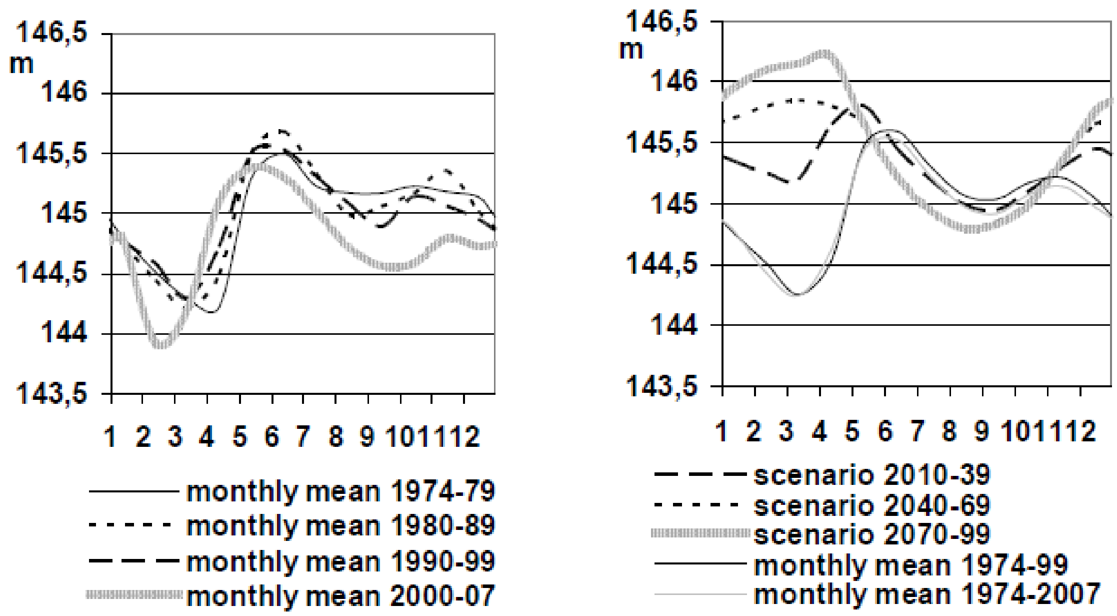


Fig. 9. Groundwater levels at Akonjoki groundwater station

The fourth example, Salla groundwater station, is situated in Northern Finland. The groundwater station belongs to the regime where the minimum groundwater level is reached at the end of winter and the annual maximum is after the spring thaw. There is no dry peak during the summer because the summer period is short and it usually has high precipitation. The summers of 2002 and 2006 were warm which led to decreased groundwater levels during the annual minimum of wintertime. The summer of 1999 was also warm. The summers of 2000-2007 have not been exceptionally dry but the monthly means have still decreased slightly. The climate scenarios predict that the decreas-ing trend of summertime will continue and that the summer period will become longer and tempera-tures will rise. The winter period will shorten. Dryness will increase during summertime whilst wetness will increase during wintertime.

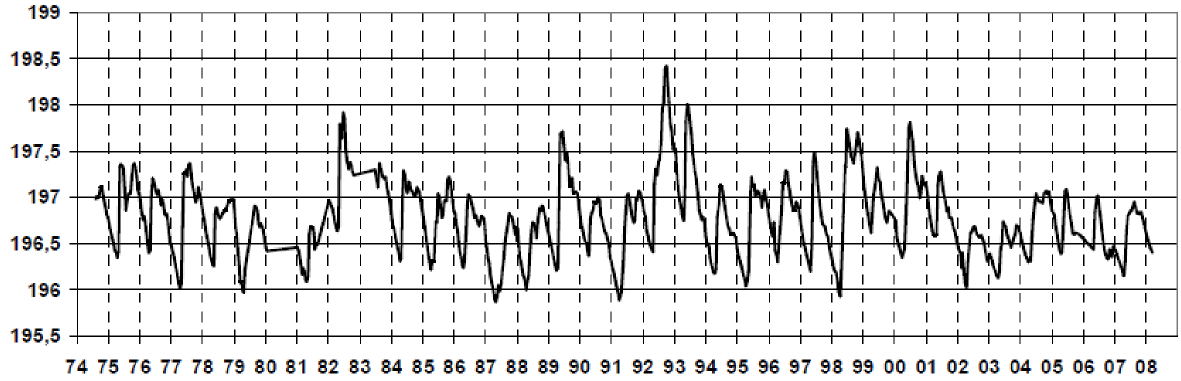
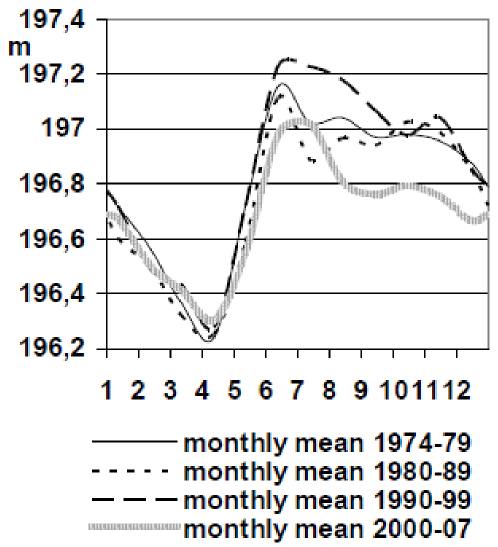


Fig. 10. Groundwater levels at Salla groundwater station



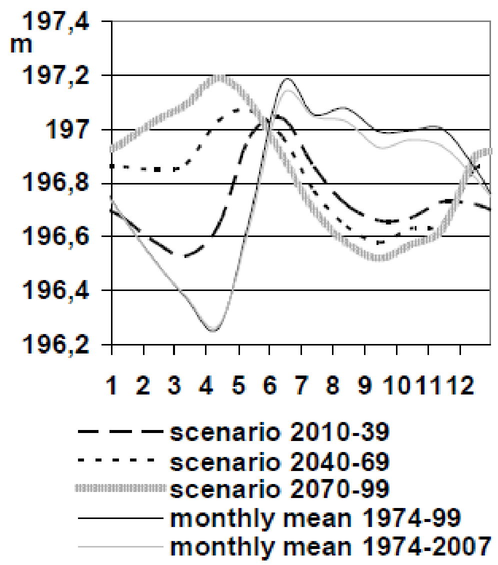


Fig. 11. Monthly means and scenarios (with the mean climate scenario) for Salla groundwater station

IV. Conclusions

Changes in groundwater annual fluctuation is common, but the variations in levels during the long observation period from 1974- 2007 show that the annual groundwater tables in Finland have changed. The winters have become shorter and the groundwater regimes have moved northward. The climate change scenarios for temperature and precipitation together with the Watershed Simulation and Forecasting System project that this trend will continue. The prognosis is, that winters will shorten, and the summer periods will become longer and temperatures will rise. Dryness will increase during summertime while wetness will increase during wintertime. The evaporation of summertime and the prolonged growth period will eventually specify the future behavior of groundwater levels.

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