Nordic Hydrology, 21, 1990, 185-194

Effect of Climate Variability and Change in Groundwater in Europe

Keynote paper presented at the Conference on
Climate and Water, Helsinki, 11-15 September, 1989

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Public water supply in Europe relies very heavily on groundwater. Recharge of groundwater takes place mainly in the winter months. An analysis of winter rainfall data shows that current recharge rates are abnormally high, and that during several periods in the past the rate has been less than half the current value. A return to such low values could have catastrophic consequences, but even more modest drops would be serious. Useful predictions must be based on climatic models and the full use of climatic, paleohydrological and historical data.

Introduction

In Europe groundwater is the most important freshwater resource for public water supply and industry.

From an analysis of the groundwater recharge in Denmark and of rainfall in Europe it will be demonstrated that periodic variations and climatic change are very important for the water industry and thus also for future economic development.

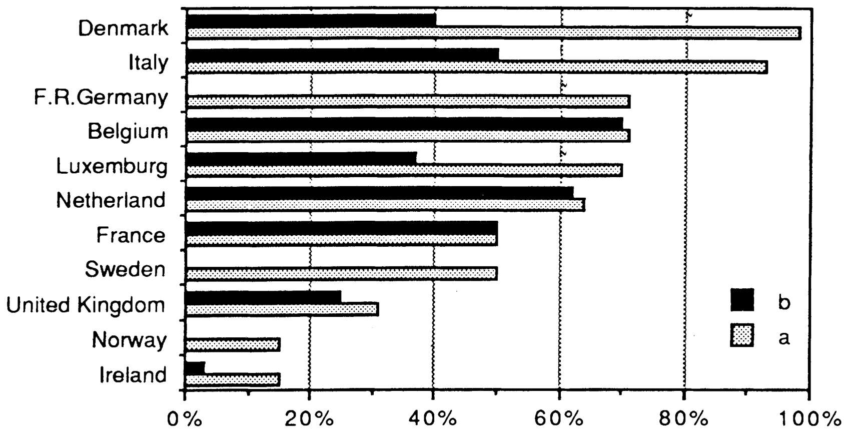

Fig. 1. a) Groundwater as a percentage of total water use.
b) Groundwater abstraction as a percentage of potential resources. Commission of the European Communities (1982).

Groundwater in Europe

There are several reasons for preferring groundwater to surface water for water supply purposes:

1) Groundwater generally has a high and stable quality and is protected against pollution.
2) Groundwater can be abstracted independent of season and of variations between years.
3) Groundwater has no evaporation loss from the reservoir.

Data published by The Commission of The European Communities (1982) show that in Europe more than half of the water supply comes from groundwater. The current pattern, shown in Fig. 1, reflects both the distribution of natural resources and the effects of tradition.

In future as commercial and domestic demand rises the need for groundwater will increase.

Since 1850 the population of Denmark has increased from 1.5 to 5.2 millions, a factor of 3.5. In the same period the consumption of drinking water increased from 50 litres per inhabitant per day to 200 litres, a factor of 4.

As a result, the consumtion of drinking water has increased by a of factor 14 from 27 to 380 $\times 10^6$ m^3/year.

During the last 10 years there has been a slight decrease in water use in a few

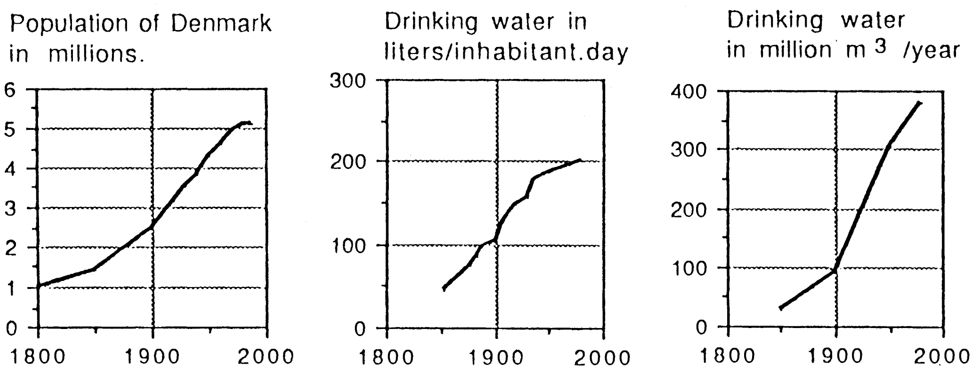

Fig. 2. The consumption of drinking water in Denmark.

European countries, largely because the increased cost of sewage treatment has motivated comsumers to limit their use of water. However, there is as yet no general decreasing trend.

As the abstraction of groundwater is very important in Europe, it is surprising that only very few have considered the influence on groundwater of climatic change and variation (WMO 1987). In fact, the water industry seems to regard groundwater as a constant water resource.

Climatic Change and Groundwater in Europe

Potential evapotranspiration in Europe is between 500 and 700 mm per year. In much of Europe the annual rainfall is between 500 and 800 mm and therefore nearly all the summer rainfall evaporates (USSR COMMITTEE of IHD 1976). On the other hand, evaporation in the winter months is very low. Winter rainfall is therefore the most important source of groundwater recharge.

Most climatologists believe that increased air pollution, in particularly with CO_2, will lead to climatic change. Regional climatic models have therefore been used to predict future changes in temperature and rainfall (W. Bach 1989 and W. Kellog 1987)

The GISS-model, predicts for example, that winter rainfall will increase in the northern and central parts of Europe (Fig. 3).

If the models are right then the water industry in these areas will get more groundwater for abstraction over the next century or two. Yet all climatic models are based on certain assumptions, so it is very dangerous for the water industry to rely on such climatic change in planning the future freshwater development.

Moreover, it is also very important to analyse the groundwater recharge in relation to short-term climatic variations.

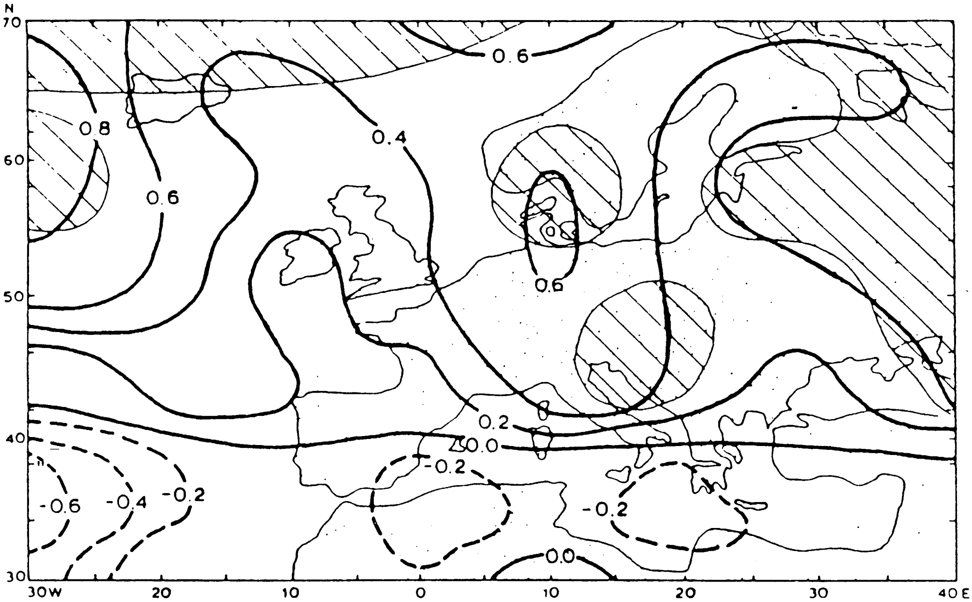

Fig. 3. Regional distribution of the change in average precipitation rate (mm/day) caused by doubling of the CO_2 concentration, as calculated by the GISS-Model (Goddard Inst. for Space Studies, New York, USA).
Shading indicates changes that are statistically significant at the 5% lever (Bach 1989).

Climatic Variation and Groundwater

Variations with periods up to 5 years are not of major importance to the groundwater industry. Medium term variations (*e.g.* 5-30 years) will have a great effect on the groundwater recharge. In his 1981 paper R. C. Tabony described the main patterns of European rainfall. The location of stations with continuous rainfall series is shown in Fig. 4 a). The network was divided into 15 regions indicated by the dashed lines.

Ten-year means of the annual rainfall in the 15 regions for the period 1861 to 1970 are shown in Fig. 4 b). These are calculated from standardized anomalies of

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Fig. 4. a) Stations with long rainfall time series. Dashed lines divide the area into 15 regions.
b) Decadal means of annual rainfall over the 15 regions of Europe (R.C. Tabony 1981).

Fig. 4 a) also shows the areas in Europe that can expect a decrease in groundwater recharge in the future because of natural climatic variation,

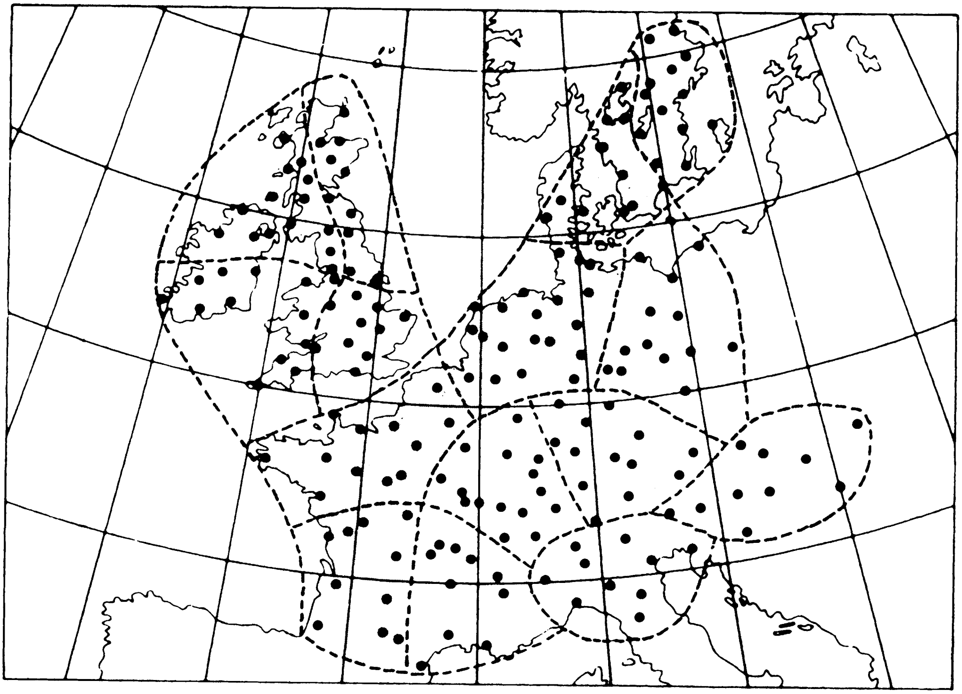
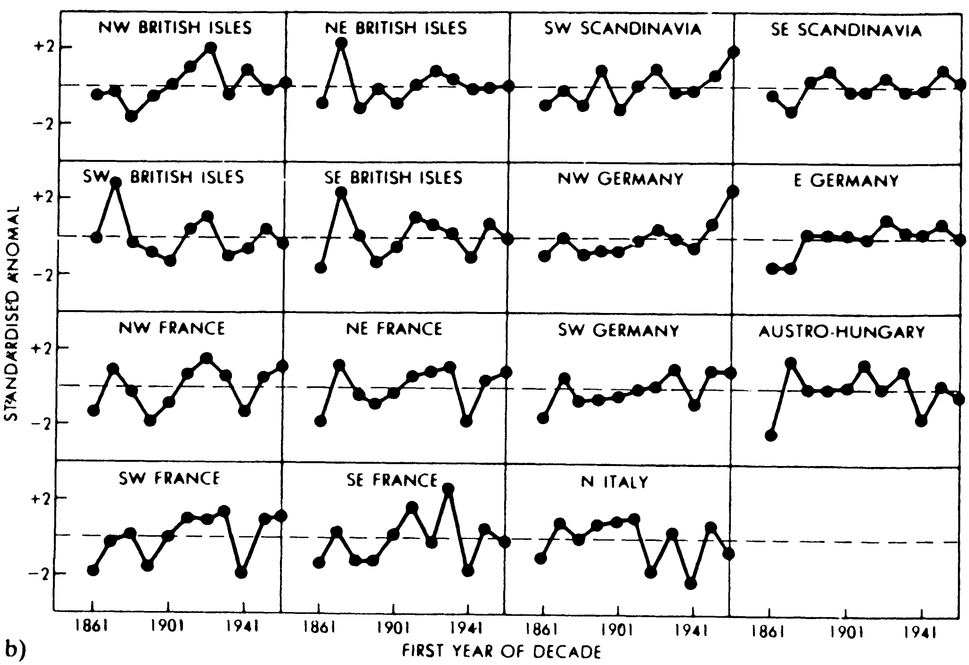


Fig. 4. a)


NW BRITISH ISLES
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NW FRANCE
NE FRANCE
SW GERMANY
AUSTRO-HUNGARY
SW FRANCE
SE FRANCE
N ITALY
+2
−2
STANDARDISED ANOMAL
1861
1901
1941
FIRST YEAR OF DECADE

b)

rainfall at each station (*i.e.* departures from the mean were expressed as multiples of the standard deviation).

Increases in rainfall are evident in a belt stretching from southwest France through northwest Germany to southwest Scandinavia. This increase is mainly a feature of the winter half-year in France and of the summer half-year in Germany.

Areas in the belt with increased winter rainfall have experienced a continuous increase in groundwater recharge through the last 30-40 years.

Groundwater Recharge in Denmark

To demonstrate the variation in groundwater recharge, the recharge in Denmark will be discussed in more detail (R. Thomsen 1978, 1987)

Fig. 5 shows the rainfall during the five winter months November, December, January, February, and March, both in the Århus-region in Denmark, and in England/Wales (data from T.M.L. Wigley 1984 and 1987, and the Danish Meteorological Institute).The Århus graph contains long and short waves. After 1900 the waves are relatively regular, but before 1900 there is a long period with very low winter rainfall. This period is very critical for the groundwater recharge.

Two similar critical periods can be recognized on the England/Wales-curve.

The Århus region has an average annual rainfall of 683 mm. On the winter curve, Fig. 5, the following periods can be seen:

1862-1985 overall average	254 mm
1864-1894 average of 30 years	214 mm
1950-1985 average of 35 years	272 mm
maximum difference between periods	58 mm

The England/Wales has an average annual rainfall of 912 mm. On the winter curve the following periods can be seen:

1766-1985 overall average	383 mm
1775-1800 average of 25 years	330 mm
1950-1985 average of 35 years	417 mm
1900-1985 average of 85 years	418 mm
maximum difference between periods	88 mm

The importance of this differences become obvious when it is compared with the average base flow in streams. In the Århus region baseflow is 91 mm.

In great parts of Europe the surplus river water resources is 100-200 mm per year (USSR COMMITTEE of IHD 1976).

Compared with this 60-80 mm is a large amount of water.

Fig. 5 shows that the winter rainfall in the Århus region has been increasing through the last 30-40 years.

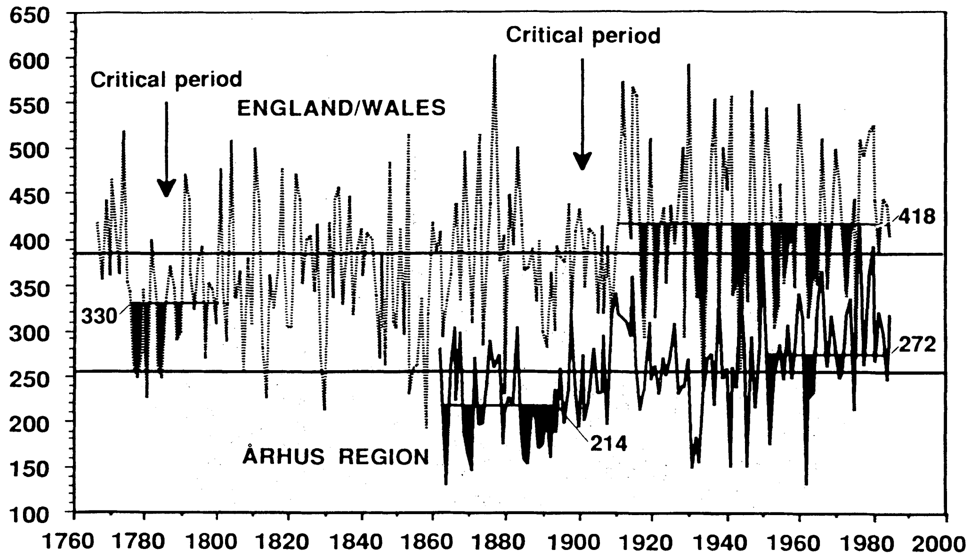

Fig. 5. Winter rainfall England/Wales (stippled line) and Århus region (solid line). Sum of five months, November to March, in millimetres.

The increased winter rainfall and groundwater recharge in the Århus region can be demonstrated by an example.

In 1971 new water works were built in an area close to the town of Silkeborg in Jutland. There is no other major groundwater abstraction in the area.

The water works abstract 2.4 mio m^3/year *i.e.* 7,000 m^3/day. The drawdown in the monitoring wells was predicted to be 2 metres. Because of the increased groundwater recharge the groundwater table has in fact risen one metre. Not surprisingly, the local Council thinks that this is really the best water works they ever built!

Estimate of Groundwater Recharge

It is possible to get a good estimate of the groundwater recharge from rainfall by means of a simple model.

The model is a bucket with an overflow. the model takes into account the potential evaporation, root-zone capacity and the vegetation. The root-zone capacity is defined as the amount of water that is available to the plants for evaporation. The maximum water content in the bucket is equal to the rootzone capacity. Only when the root-zone capacity is filled can excess water percolate to the groundwater.

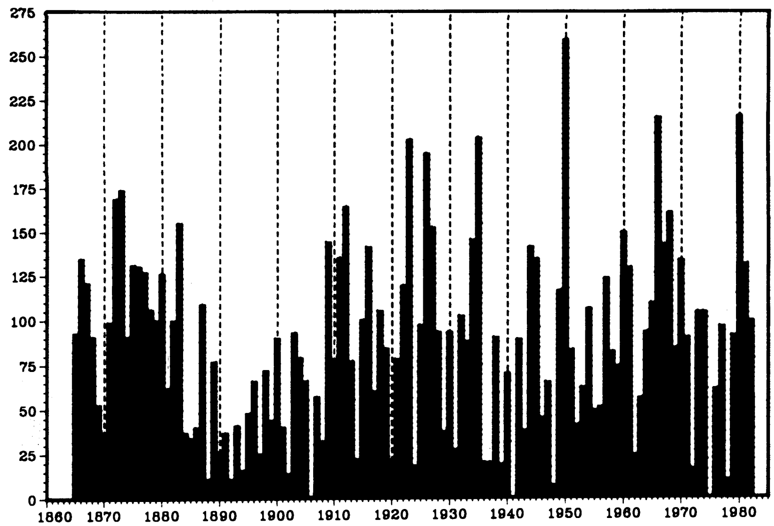

Fig. 6. Annual groundwater recharge on Samsoe in mm/year (the calculation assumes that the ground is covered with grass) R. Thomsen (1978).

The monthly groundwater recharge has calculated for the island of Samsoe with an annual rainfall of 550 mm/year (R. Thomsen 1987).

Fig. 6 shows the calculated groundwater recharge on the island Samsoe with an annual rainfall of 550 mm/year.

The winter rainfall pattern on Samsoe is similar to the winter rainfall in the Århus region.

The following periods can be abstracted from the calculations:

1964/65-1982/83 average of 19 years	102 mm
1884/85-1908/09 average of 25 years	46 mm

The period with low recharge can be confirmed by direct observation. In 1896 the geologist Victor Madsen did field work on the island, Victor Madsen (1897). To his surprise he observed that the island had no lakes, and all the streams were dry. Earlier there had been water mills on the island. The last one ceased working in 1851.

Implications for Water Supply

The water industry in Denmark bases its development plans on the increase in groundwater recharge through the last 30-40 years, which is the highest groundwater recharge recorded through the last 125 years.

In many regions in Denmark present groundwater abstraction is already very close to the limit of the resources. In some areas the abstraction rate is now already greater than the recharge.

For example the water demand in the Århus region has lowered the groundwater-table by more than 10-30 metres through the last 40 years.

For the Århus region, with an area of 730 km^2, the water administration is now going to use an hydrological SHE-model for water resource planning and future monitoring of the water balance and water quality. SHE – the European Hydrological System, developed jointly by the Danish Hydraulic Institute, SEGREAH (France) and Institute of Hydrology (U.K.). In the Århus region the water balance is already negative. Furthermore, the groundwater supply is threatened by decreased winter rainfall, and also by contamination from saltwater intrusions, farming and more than 65 waste and chemical dumps.

If the groundwater recharge should ever be reduced to half of the present rate (such as occurred in 1880-1910) the water industry in many regions of Denmark would be faced with catastrophy: water shortage, salt water intrusions. Some streams and wetlands might dry up completely.

The same problems are likely to occur in the belt shown in Fig. 3.

Conclusion

All hydrologist and water engineers know that groundwater recharge is affected by climatic variations. However, very few seem to realize just how sensitive the system is, and what the implications of this are. Thus in most of eastern Denmark the groundwater recharge at the end of the last century was only half of the present rate. There is thus little reason to believe that the present rates will be maintained or even increased, and much to suggest that decreases will occur at some time in the future. Yet most water resource planning does not take account of this possibility.

R. C. Talbony's 1981 study of European rainfall permits us to estimate future changes on the basis of past variations. His data suggest that areas in Europe can expect a decrease in winter rainfall. Since recharge mainly takes place in the winter this would lead to a major drop in the recharge. This is particularly likely in southwest Scandinavia, western and northeastern France, as well as Belgium. In some parts of Europe such a decrease could have catastrophic consequences if not addressed properly.

Planning for such an eventuality involves hydrological modelling and the full use of available time series. Such series must be supplemented by the use of historical data, palaeohydrology and climatic models. Climatic research is therefore very important for groundwater resources and thus for the economic development of Europe.

Acknowledgements

Thanks to C. Aub-Robinson, Geologisk Institut, Århus Universitet, for valuable comments on the manuscript.

The Article is a keynote paper presented at the Conference on Climate and Water, Helsinki, 11-15 September 1989.

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First received: 13 November, 1989
Revised version received: 23 February, 1990
Accepted: 1 March, 1990

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