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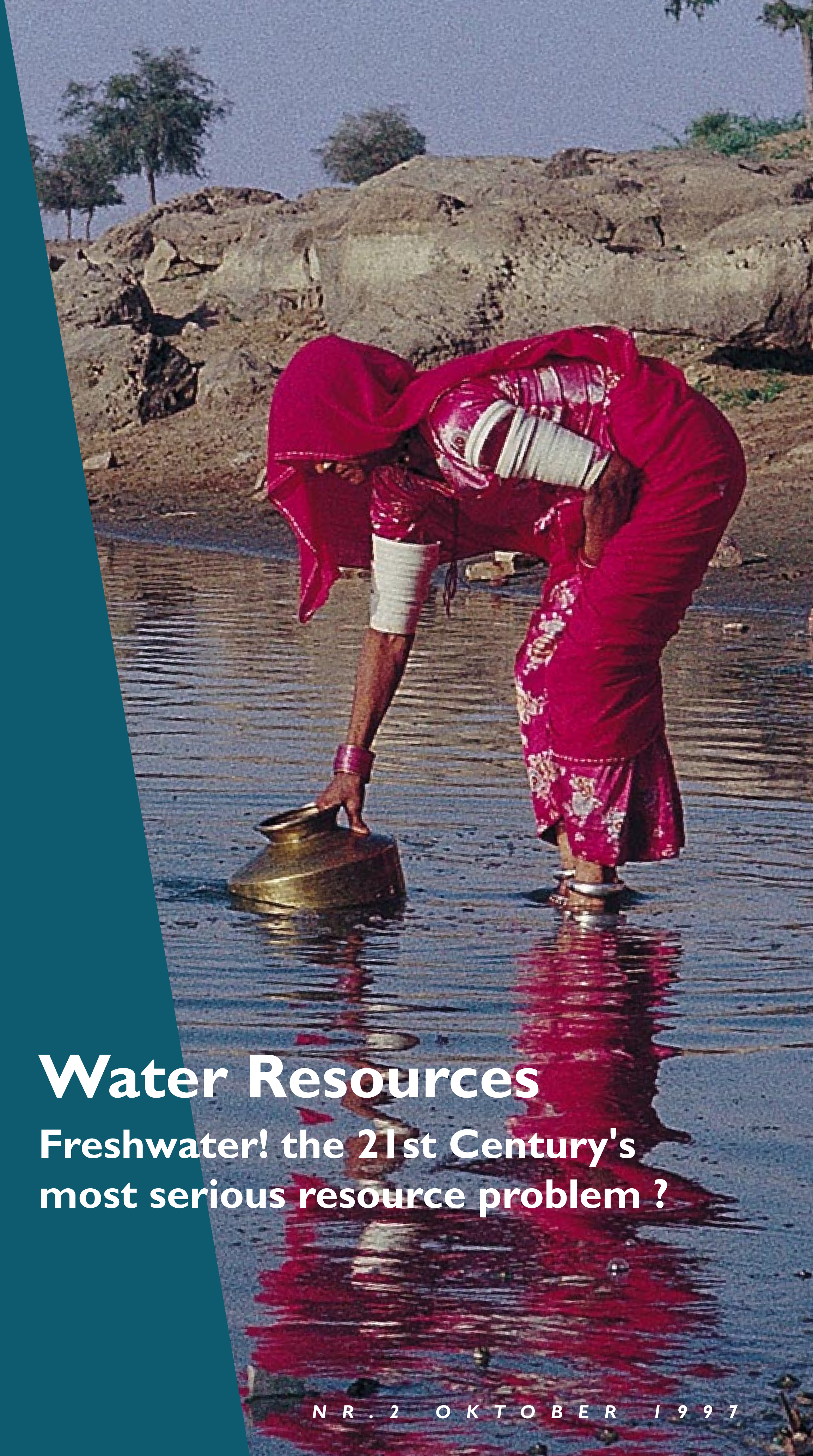


Water Resources

Freshwater! the 21st Century's most serious resource problem ?

NR. 2 OKTOBER 1997

The global water resources

Water is in a natural cycle of constant change between precipitation, evaporation and runoff. Some of the precipitation which falls over land areas evaporates. The portion of the precipitation that does not evaporate is called the net precipitation. On the earth's surface the net precipitation then flows either to streams, in some areas to drains or infiltrates further into the earth to recharge groundwater. Most of the groundwater flows slowly through aquifers out to streams, lakes and the sea.

The amount of groundwater recharge and the hydrogeologic conditions control the distribution and age of groundwater, as well as how quickly contamination from the surface will spread in groundwater. Groundwater is found in pore spaces between grains of sediments and in cracks and fractures in clay and rock. The ability of the earth formations to conduct water is due to permeability or hydraulic conductivity. This interconnectivity between pore spaces and/or fractures controls groundwater conditions and with that the opportunity for water supply. Groundwater flows from places where there is high water level or pressure to places with low water level or pressure; for example from a hilly region to a stream, lake or pumping well.

Freshwater, the Main Problem of the 21st Century

Accessible freshwater is unequally distributed around the globe. The geographic distribution of freshwater is dependent upon climate, topography and geology. Furthermore, there can be time variations in the quantity of regional water resources in response to prolonged changes in climate. Water resources are of fundamental importance for many of societies conditions. The growing water shortage as a consequence of an increasing world population and rising per capita water consumption threatens many aspects of society both globally and in individual countries.
This includes:

- water quality and the populations health
- utilization of water resources and economic conditions
- water resources and food production/land use
- water resources and energy production/use
- water shortage and social/political conflict

Worldwide, the estimated precipitation over land areas is about 113,000 km^3/yr and estimated evaporation is 72,000 km^3/yr. From this, the net precipitation is approximately 41,000 km^3/yr or approximately 7690 m^3/yr per inhabitant on the earth.

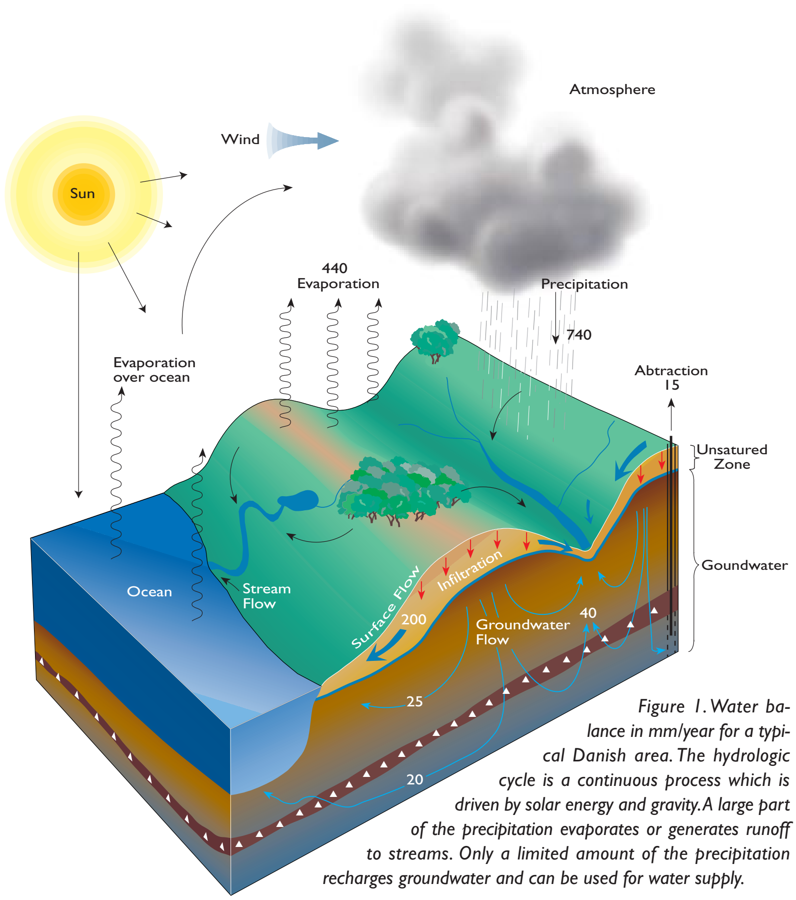


Figure 1. Water balance in mm/year for a typical Danish area. The hydrologic cycle is a continuous process which is driven by solar energy and gravity. A large part of the precipitation evaporates or generates runoff to streams. Only a limited amount of the precipitation recharges groundwater and can be used for water supply.

Water Balance Calculation

$$N - E_A = Q_o + P + Q_b + M$$

where:

- N = *Precipitation*
- E_A = *Actual Evaporation*
- Q_o = *Surface water flow*
- P = *Groundwater abstraction*
- Q_b = *Groundwater discharge to streams, lakes and the ocean*
- M = *Change in groundwater storage*

Approximately 12,000 km^3/yr of water contributes to groundwater reacharge, while 29,000 km^3/yr flows directly to streams. In actuality only 10 to 30% of the net precipitation can be exploited for water supply needs. Assuming that the available renewable freshwater resource exploitation is 15% of the net precipitation, then the exploitable water resource globally is around 6,000 km^3/yr.

The global total water consumption was 3,800 km^3/yr in 1995. This equals to an

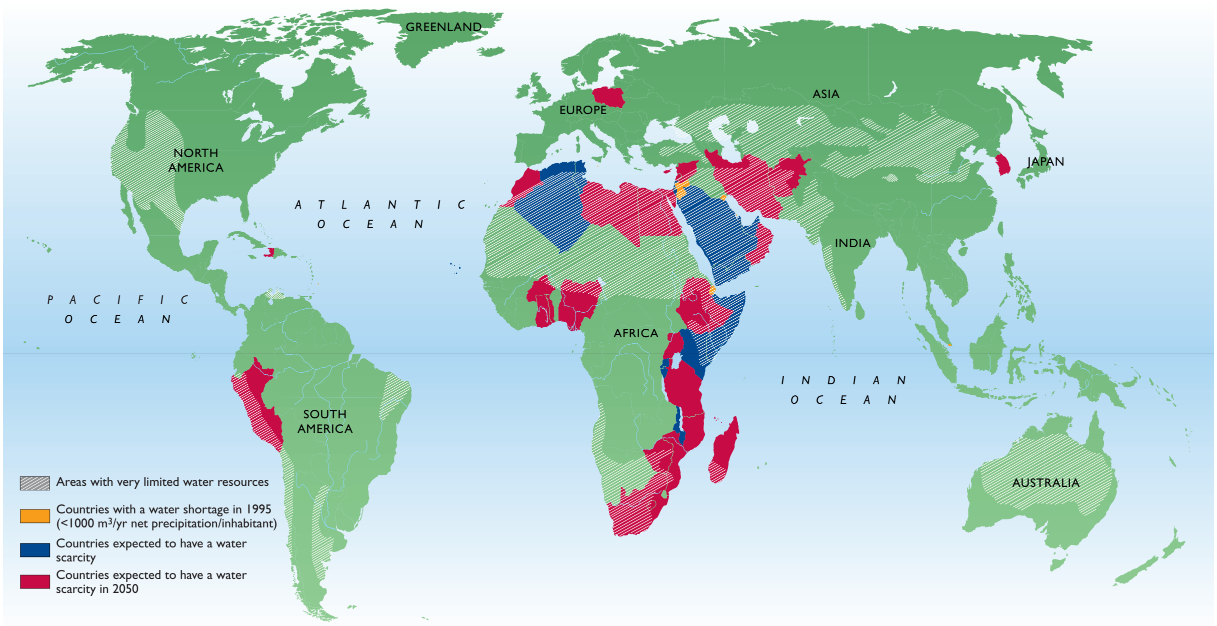


Figure 2. Areas around the world where the largest problems exist concerning the quantity of water resources. Arid regions are depicted by a hatched pattern. Due to increasing population and rising water use the number of countries experiencing water shortages is also increasing. Shown are countries which experienced water scarcity in 1950, 1990 and those expected to experience scarcity in 2050.

Water Shortage Overview

In 1995 only 7 countries belonged in the water shortage catogory: Bahrai, Barbados, Djibouti, Jordan, Kuwait, Malta and Singapore. In 1990 the list contained 20 countries including Algeria, Burundi, Israel, Kenya, Malawi, Rwanda, Saudi Arabia, Somalia, Tunisia and Yemen.

In the year 2050 it is anticipated that the list will grow to include 26 countries including the following: Afganistan, Burkina Faso, Cyprus, Egypt, Ethiopia, Ghana, Iran, Lebanon, Libya, Marocco, Mozambique, Nigeria, Syria, Tanzania, Uganda and Zimbabwa. Between 1 and 2.5 billion people in the year 2050 will live in a country with a water shortage, this accounts for approximately 10 to 20% of the worlds population.

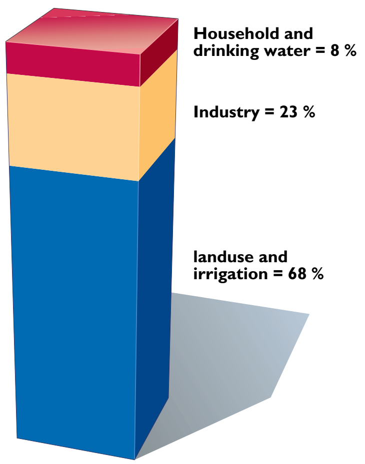


Figure 3. Division of the global water use in percent for 1995.

average use per inhabitant of 660 m^3/yr. The global water consumption increased 4-fold from 1955-1990 as a consequence of a 2-fold increase in the worlds population and an increase in the use of water per person. Agriculture uses the most water globally at 68%, while industry uses 23%. Household and drinking water use represents only 8% of the total water usage (see Figure 3).

The worlds population is predicted to double around the year 2050 in relation to the 1995 population of circa 5.7 billion people. Estimates show that the global water resources can not sustain a 4-fold increase. This is why water is considered to potentially be the 21st centuries most serious resource problem.

Regional Differences and the Consequences

In some parts of the world only a limited part of the sustainable exploitable water resource is being used. Due to an unequal distribution within the different regions and an increase in pollution of unknown extent it is estimated that in many places in the world the groundwater resource is being fully exploited.

Today some of the largest pollution problems are related to global water resources:

- untreated waste water discharge(s)
- nutrients and pesticides from intense land use
- heavy metals from industrial pollution
- chlorinated organic compounds which slowly degrade

There is considered to be a water scarcity in countries where the net precipitation is less than 1000 m^3/inhabitant per year.

A consequence of the rising water use, especially for irrigation systems, there has been an increase in the number and size of water supply projects which have started over the last 35 years. This has caused massive changes to the global water environment and has furthermore resulted in extensive threat to and destruction of rivers and water systems basic ecological functions.

Water resources are currently being over exploited in many of the worlds important food producing regions. In the worst case, this can result in the emptying of groundwater reservoirs. This applies to large regions of the USA, Mexico, The Arabian Peninsula, northern Africa, parts of India, North China and many areas around large cities in Southeast Asia and Europe.

Access to clean drinking water is a universal human need. Globally, it is estimated that 20% of the worlds population does not have access to clean drinking water, while 50% live with substandard sanitary conditions. Health is directly dependent upon access to clean drinking water and proper sanitary conditions.

The current situation of global water resources is that there is expected to be a true water crisis around the corner brought about by a continuous population increase and rising water use per inhabitant. In addition comes the large problem of groundwater contamination. For these reasons, there is the need for concrete initiatives, for example:

- greater protection of the water environment
- more efficient use of water especially in regions with a water shortage
- more equitable sharing of water resources
- greater participation by the public in the decision making process.

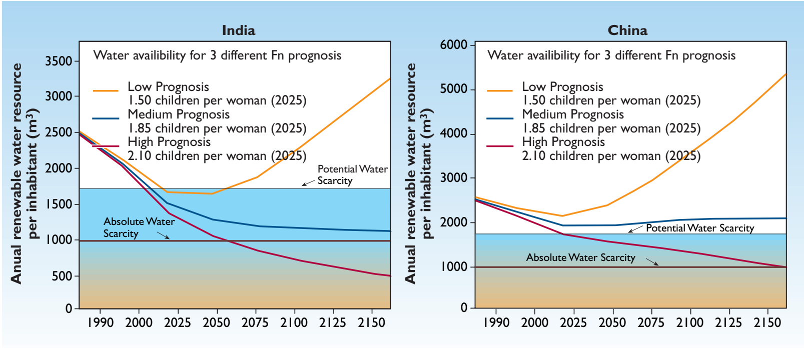


Figure 4. Range of the renewable freshwater resource per inhabitant versus time in India and China based upon 3 different FN population growth scenarios.

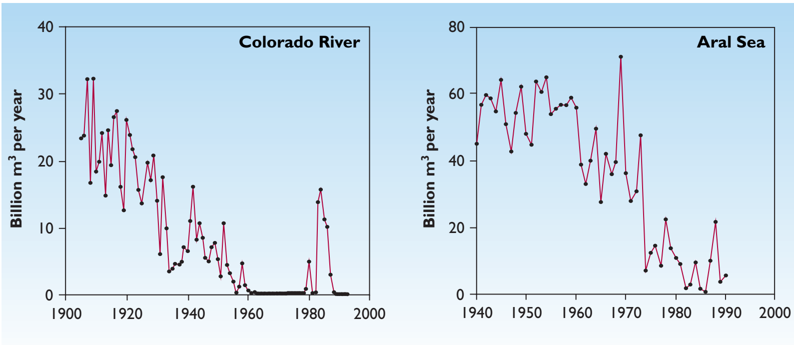


Figure 5. Flow in the Colorado River, USA and flow to the Aral Sea in Central Asia. Source: USGS, International Boundary and Water Commission.

Figure 6. In order to obtain potable water for their village in India, residents have punctured a water supply pipe which carries clean drinking water to the nearby city of Jaisalmer.

Water Resources in Denmark

Pesticides at concentrations greater than acceptable limits have been found in 3% of the investigated water wells in Denmark.

Previously, it was thought that groundwater in Denmark was well protected from pollution due to the depth of the groundwater reservoirs and the thickness of overlying clays. It was not until relatively recent that groundwater pollution problems were recognized in Denmark with the exception of local discoveries of pollution from oil and gas stations and waste water infiltration systems.

In the 1960's and 70's efforts were concentrated mainly on mapping and utilization of the water resources. Since the early 1980's investigations brought into awareness the problems associated with landfills, bulk storage terminals, industrial facilities and intense land use. Recognition of the problems initiated a series of research activities upon which the results provided the basis for regulations related to water resources. In the beginning of the 1990's intensive systematic investigations of pesticides in groundwater provided alarming results. Pesticides and their degradation products were more widespread in the groundwater environment than expected. In 1995 traces of pesticides and degradation products were found in 10% of the investigated wells and in 3% of the wells levels were above drinking water standards. In present-day Denmark, groundwater contamination has reached a proportion that constitutes a threat against the traditional, decentralized water supply system based upon simple water treatment methods.

Freshwater Resources quantity and variation

The viable exploitable groundwater resource in Denmark is greater than the total quantity of abstracted water. The latest comprehensive calculation made in 1992 estimated that the exploitable water resource is in total 1.8 billion m^3/yr, which is greater than the present water use of approximately 1 billion m^3/yr. The majority of the water supply is based upon abstracted groundwater (99%). Surface water is used in limited quantities. In some parts of the country there is enough water and in other parts there is a water shortage due to significant regional variations in net precipitation.

There is significant uncertainty in the estimate of the exploitable groundwater resource quantity. In the estimation it has been considered that certain areas in general have unfavorable conditions for groundwater abstraction and that the natural water quality in other places is so poor that the water can not be used without treatment. Futhermore, the environmental state in streams and wetlands place limits upon the extent to which freshwater resources can be exploited. In the meantime, two essential conditions have not been considered:

- pollution
- influence of long term climate variations.

An estimation of the exploitable water resource which does not include contaminated water and the influence of long term climate variations (especially presence of drought periods) provides a considerably reduced estimate of the sustainable water resource on the national level as compared to the 1.8 billion m^3/yr estimate.

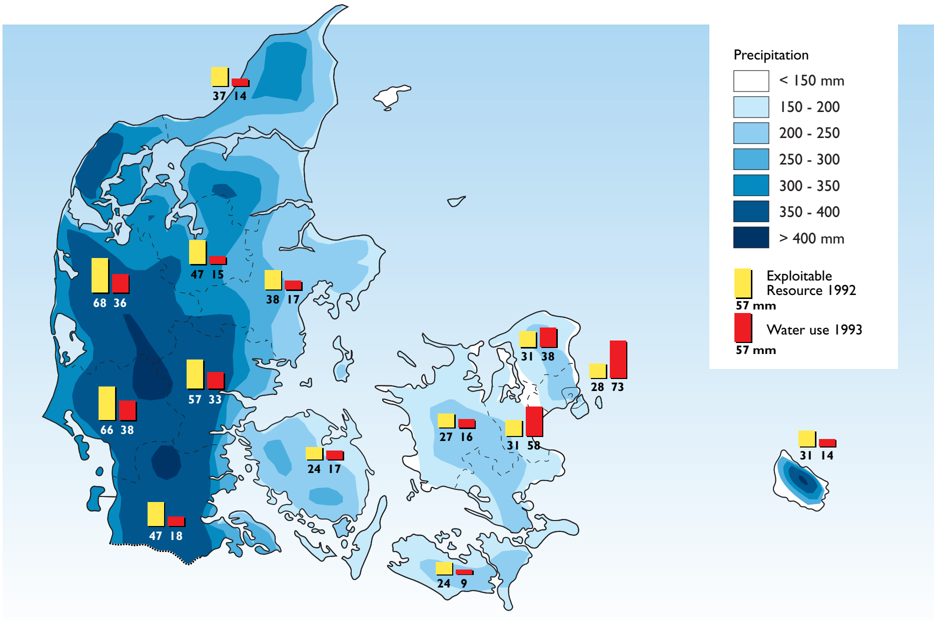


Figure 7. The net annual precipitation across Denmark in millimeters (mm) is shown in blue. The exploitable water in mm/year is represented by the yellow bar. Water use in mm/year is represented by the red bar. The net precipitation and thereby the quantity of the exploitable water resource is largest in southwestern Denmark and smallest in central and eastern Denmark. In the Copehagen area in eastern Denmark the water resource is over utilized.

Water Use

Recovery and use of freshwater in Denmark increased through the 1970's, remained constant during the 1980's and has decreased since 1989. In Figure 9 are shown trends in industries, public waterworks and irrigation water use. The categories are not completely unequivocal. Many industries are supplied by public water works, so the total industry use is considerably greater than represented. The category irrigation covers water supply in connection with land use, i.e. crop irrigation, livestock, and fish farms. The strong focus on water conservation and increased taxes on water use in recent years

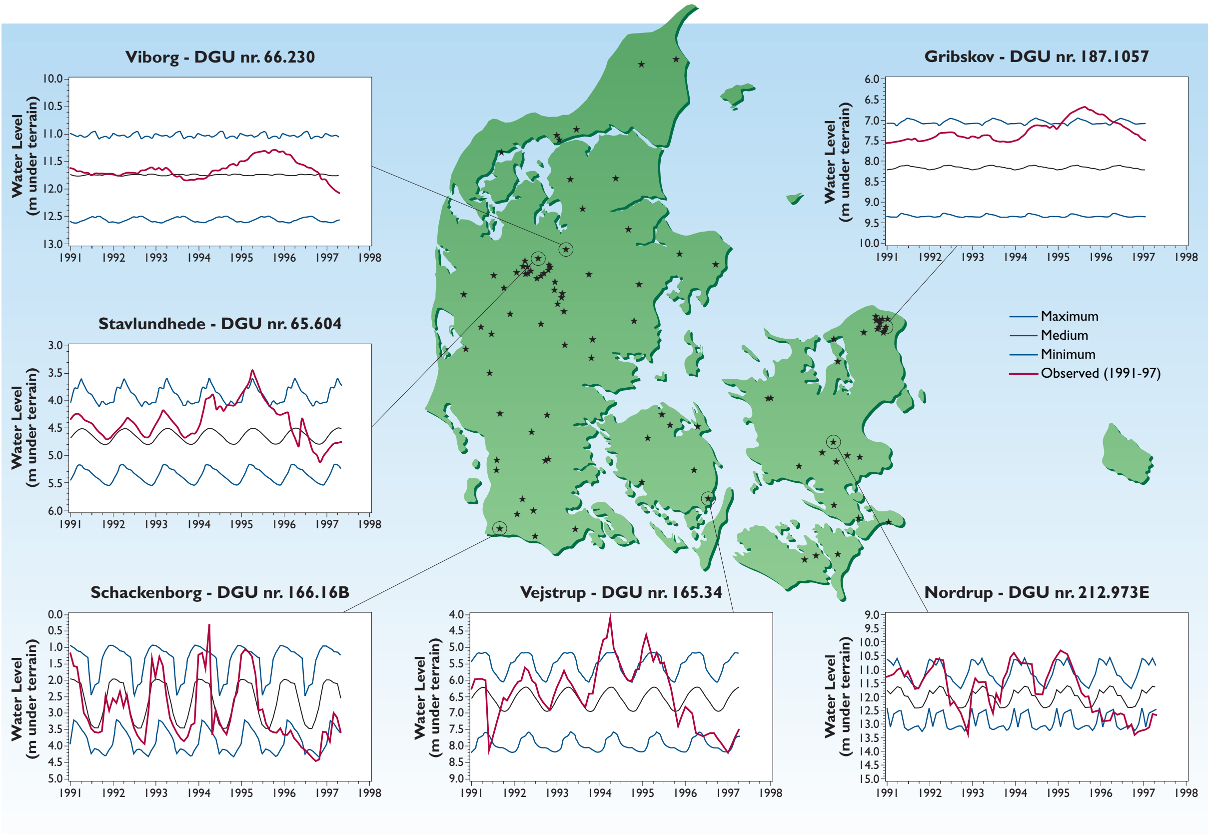


Figure 8. Groundwater level measurements (red curve) from 1991-97 are compared to the annual average maximum, median and minimal groundwater levels for the period 1971-90. Most of the groundwater recharge occurs during the winter when the plant uptake and evaporation is at a minimum. The early and mid 1970's were a dry period and caused groundwater levels to be below normal. The period 1980-95 has been relatively wet and groundwater levels have been high. The past two winters have been dry and resulting in minimal groundwater recharge.

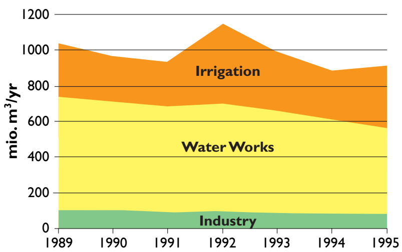


Figure 9. Water use by agriculture, water works and industry during the period from 1989 to 1995. Groundwater abstraction and use increased in the 1970's, remained relatively constant during the 1980's and has decreased since 1989.

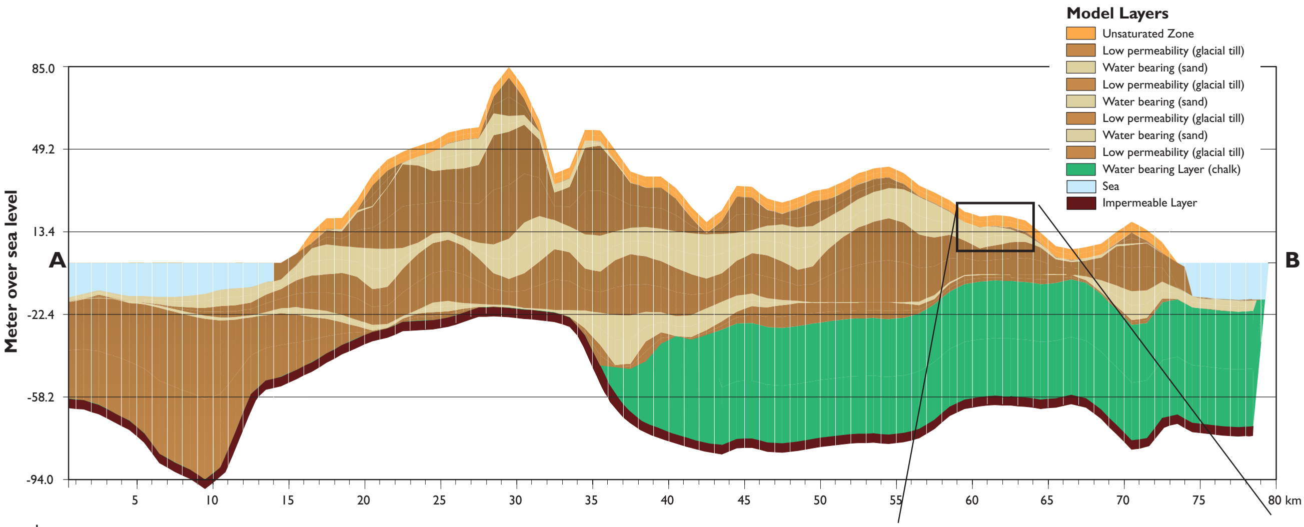
has had a visible effect regarding household and industrial use.

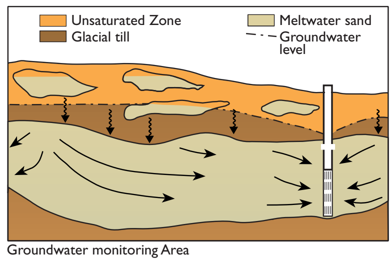
Over the past 250 years considerable changes in the amount of precipitation have been measured and the influence on the groundwater resources are being determined. For example, a period of abnormally low precipitation has been identified just before the turn of the century and in the last 25 years we know of a period with low precipitation which occurred in the early and mid 1970's. The period from 1980 to 1995 has been relatively precipitation rich. The last couple of years since the fall of 1995 have been unusually dry with limited precipitation during the winter and relatively hot, dry summers accompanied by a large irrigation demand. This has resulted in a marked decrease in groundwater levels especially in southern, western and northern Jutland. By the end of 1996 decreasing groundwater levels were also observed on many islands and in parts of central and eastern Denmark.

The National Water Resource Model

GEUS has carried into effect a project for the Ministry of Environment and Energy in order to calculate a more precise estimation of the quantity of the water resource and distribution in relation to the rather rough estimates which were the basis for earlier estimates of the available national resources. The purpose of the project is to setup a water resource model for the entire country (the DK Model). This will include the time dependent variation and regional distribution as well as an estimation of the possible future water consumption.

The DK model is based upon the comprehensive information in GEUS' archives on geology and hydrogeology which contain information from more than 250,000 wells





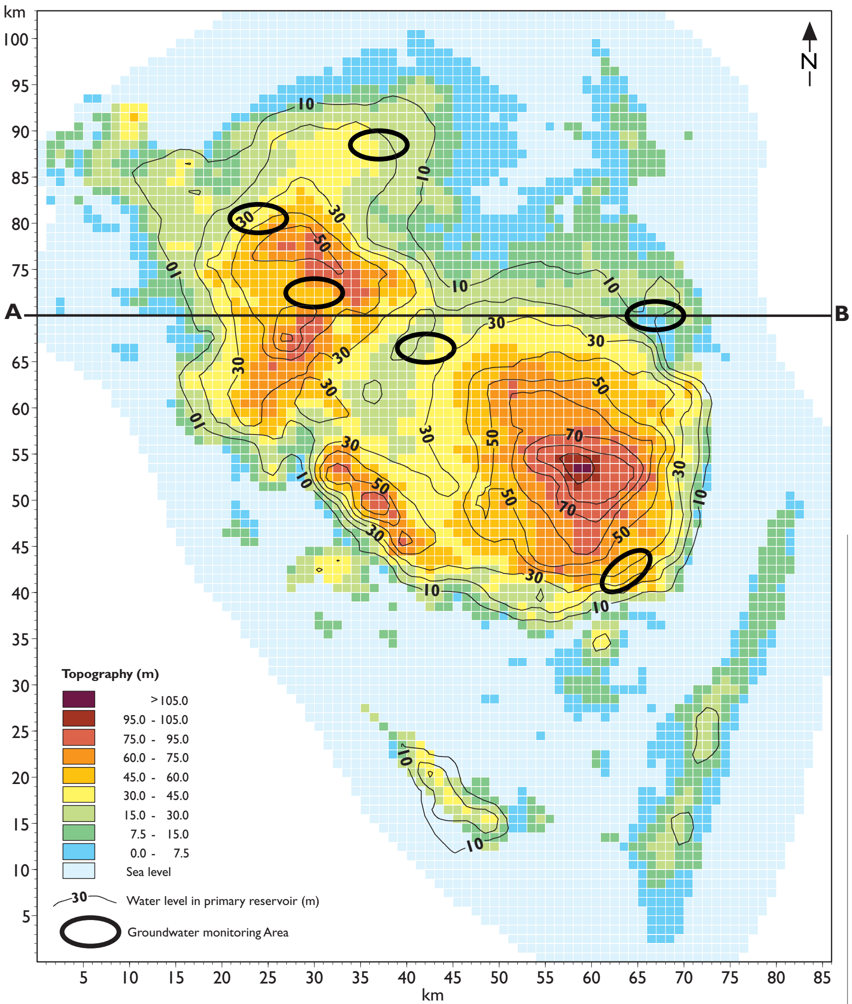


Figure 10. Geologic cross-section A-B through Funen which depicts the layers in the DK Model. The model is descretized horizontally into 1 by 1 km grid cells. The location of groundwater monitoring areas on Funen are shown on the map to the left.

drilled for supply purposes. The time plan for the setup of the model is as follows: in 1996 Funen, in 1997 Zealand, in 1998 southern Jutland and in 1999 northern Jutland. Here the first results and experiences from Funen will be shown.

The MIKE SHE system, developed by the Danish Hydraulic Institute, is used as the basis for the setup of the DK Model. MIKE SHE is a physically based numerical model which simulates the most important flow processes in the land phase of the hydrologic cycle. MIKE SHE can simulate overland flow, stream flow, unsaturated and saturated groundwater flow and drainage flow. Furthermore, snow melt and actual evaporation can be represented.

A geological model is developed as input to MIKE SHE which represents the major groundwater bearing and low permeability layers. The model is developed based upon information from GEUS' borehole log archive (PC ZEUS) and interpretations from geologic maps. Hereby, a geological model has been set up consisting of a total of nine layers. It has been necessary to combine the upper three layers in the

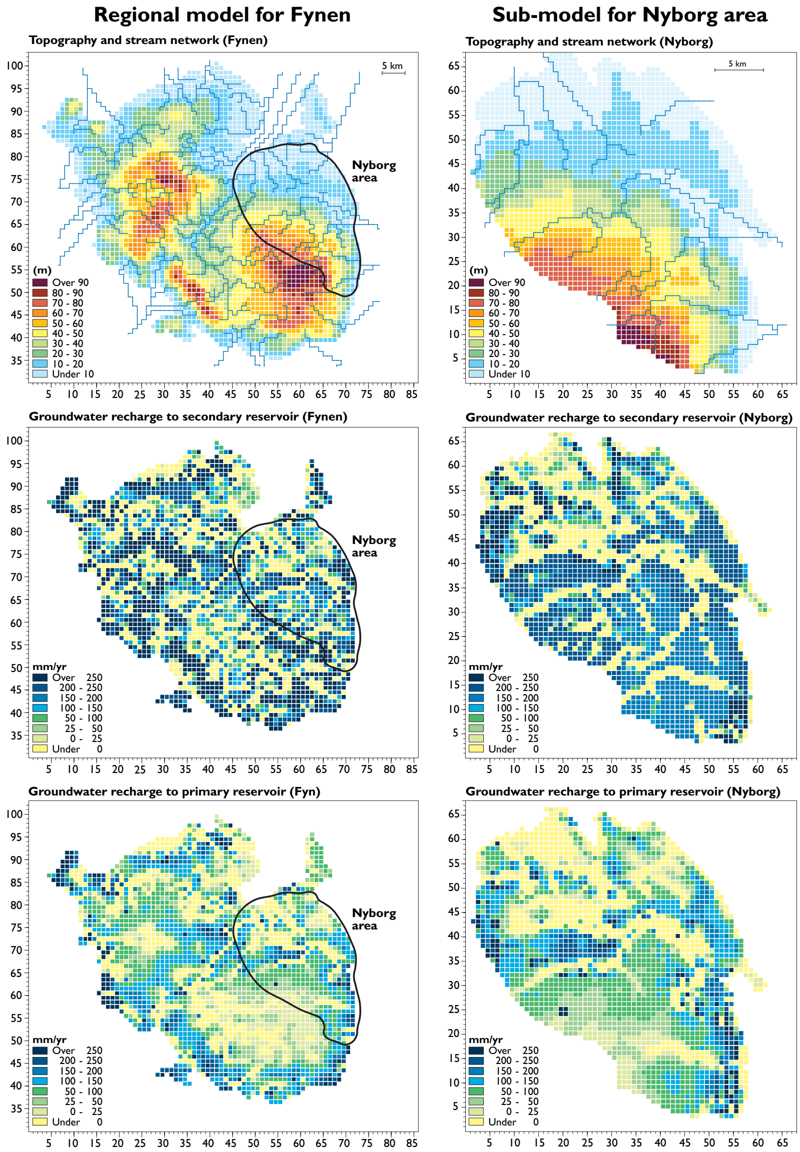


Figure 11. Topography and stream network (upper row), groundwater recharge to secondary reservoirs (middle) and the groundwater recharge to the primary reservoir (lower row) for the regional model of Funen and sub-model. Recharge is in mm/yr.

model due to numerical instabilities (Figure 10). In regard to the evaluation of the reliability of the geological model a computer program (SLICE) has been developed which is used to analyze the individual model layers using information from GEUS' borehole log archive.

There are a total of 174,000 borings in the national borehole log archive. This equates to an average of 4 borings per square kilometer.

A uniform grid consisting of 1 by 1 km cells is used to represent Funen in the DK Model (see Figure 10). This grid spacing is used in order to provide a reasonable representation of topographic and geologic variation while minimizing the number of calculation cells.

The Funen model was calibrated using measurements of stream flow and groundwater elevations. The calibrated model has been used to simulate the water balance and provide groundwater recharge estimates for the period from 1971 to 1996. The simulated water balance for the calibration period of 1989 to 1996 is compared to the simulated water balance for the period 1971 to 1990 (Figure 13B).

As seen in the simulated water balance presented in Figure 13A, the total groundwater recharge to the regional groundwater reserviors is about 75 mm/yr. The regional reservoir is the major source for abstracted groundwater. Prior to estimating the exploitable water resource for Funen, reductions in the total water quantity due to climate variations, poor water quality and unfavorable conditions for abstraction must be made. Finally, considerations of maintaining minimal stream flows and water levels in lakes puts further restrictions on the total quantity of the exploitable groundwater resource.

A simple method is used to calculate the water exchange in the root zone which describes the partitioning of water between evaporation/plant uptake and recharge to the groundwater. This simplified method of representing the unsaturated zone is coupled to the MIKE SHE system so that groundwater flow and the interaction between groundwater, surfacewater, overland flow and drain flow are represented in a rigirous, physically based manner. Results based upon the use of the simplified root zone module have been good. Calculation of groundwater recharge with the root zone module takes into account spatial variations in land use (agricultural, woodlands, and wetlands), soil type and topography together with daily precipitation and evaporation data.

The National Environmental Research Institute (DMU) is a member of the project and responsible for collecting streamflow data and creating a register of minimum flow in streams. These data are important for constraining mass balance estimates for the groundwater flow sys-

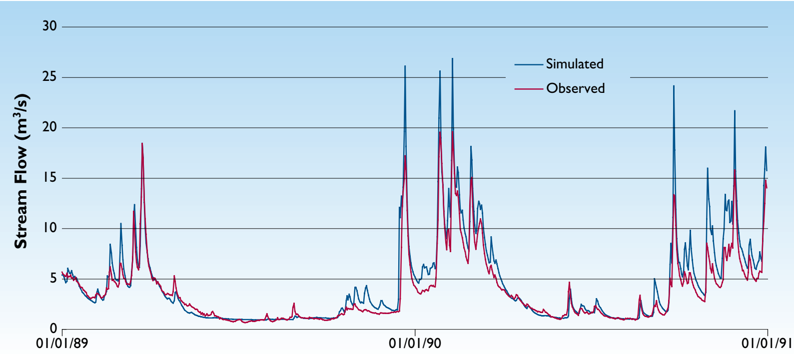


Figure 12. Comparison between model simulated and observed stream flow in Odense River during the period 1989-90.

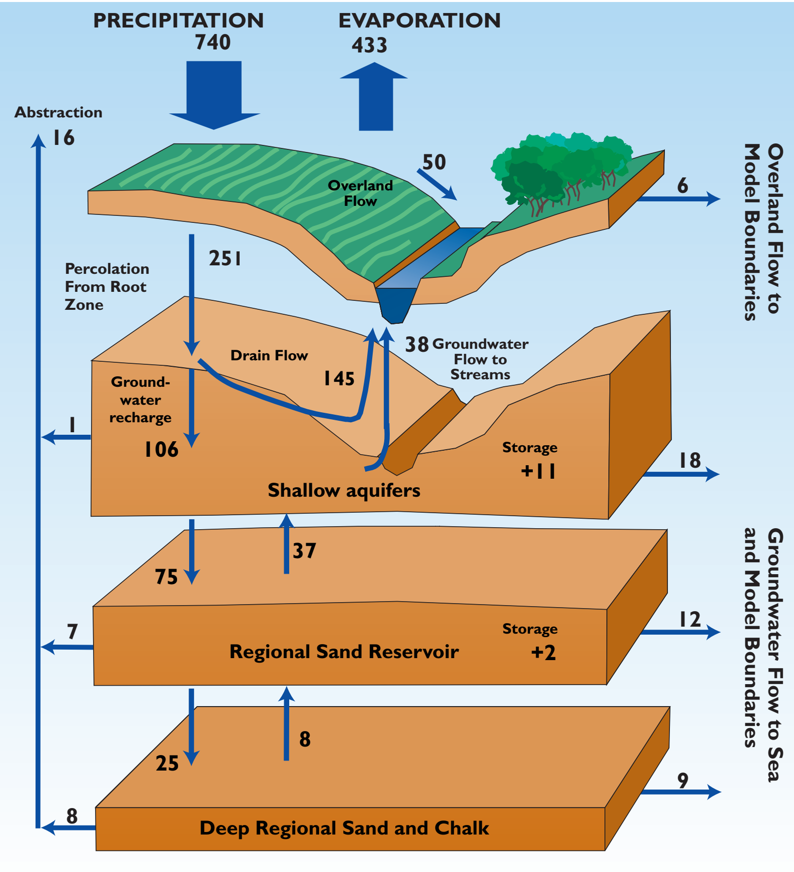


Figure 13A. Simulated water balance in millimeters for Funen 1989-96. The DK Model makes it possible to estimate changes in the water balance as a result of changes in precipitation, evaporation or groundwater abstraction.

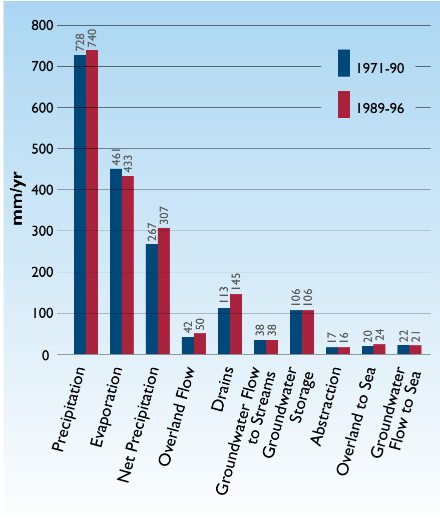


Figure 13B. Simulated water balance for Funen during the periods of 1971-90 (blue bars) and 1989-96 (red bars).

tem and improving calibration of the model when time-series stream discharge data are not available.

The Danish Hydraulic Institute (DHI) provides assistance with further development, implementation and testing of the MIKE SHE system. In connection with the DK Model, GEUS is working with DHI in further development of the MIKE SHE system in the following areas:

- a three-dimensional geologic module which provides a link between GEUS's borehole log archive and MIKE SHE
- a module for the interface with existing database programs
- a module for simulating the saltwater/freshwater interface in the groundwater zone
- a module for the transformation of parameter values between different scales.

Experience with the DK Model has shown that there is a great need for all of the modules under development if the DK Model is to be used as the basis for more detailed analysis requiring parameter transformation, solute transport and saltwater intrusion.

National Groundwater Level Monitoring Network

Regular measurements of groundwater levels provide a direct picture of changes in the quantity of groundwater. Groundwater levels vary naturally over the year with the highest water levels typically in April and the lowest water levels typically in October. Over a few years groundwater levels can change considerably relative to the normal yearly fluctuations, either due to changes in the amount of precipitation and/or groundwater abstraction. Groundwater recharge and levels are especially influenced by precipitation during the winter when plant uptake and evaporation is at a minimal.

Since the 1950's GEUS has installed and operated a nation wide groundwater level monitoring network. There is now the need to reorganize the national system in order to conduct effective monitoring of the groundwater resources quantity and development. Including being able to deliver updated information on the consequences of climate variations, water use and water abstraction on a national level. Ongoing updating and verification of the DK Model requires continuous monitoring of groundwater levels and thereby the quantity of the resource.

The monitoring network should to the highest degree possible reflect variations in geologic setting, climate and land use. The national monitoring network is set up in a manner that it can reflect the behavior of three main hydrogeologic settings:

- Shallow groundwaters direct response to climate and land use
- Deep groundwater reservoirs reflecting long time fluctuations
- Groundwater impacted by large abstraction rates.

Part of the revised national monitoring network will be established and operated by GEUS. It will consist of 20 to 30 monitoring stations, each of which consists of one well in a shallow groundwater reservoir and one well in a deep regional reservoir. These stations will be instrumented for continuous monitoring and eventual on-line transmission of water level measurements.

Another part of the monitoring network will be established and operated by the counties. These networks will consist of 10 to 50 monitoring wells per county. The monitoring wells will be situated so that they are representative of groundwater reservoirs response to large groundwater abstraction rates, mostly, but not solely, in areas designated as vital drinking water areas.

Results from the DK Model are used in selecting localities for wells in the national groundwater level monitoring network. The monitoring network will be completed in 1999 and included with the groundwater monitoring related to the Action Plan for the Aquatic Environment. GEUS will issue a quarterly newsletter on the groundwater situation in Denmark when the reorganization of the national monitoring network is completed.

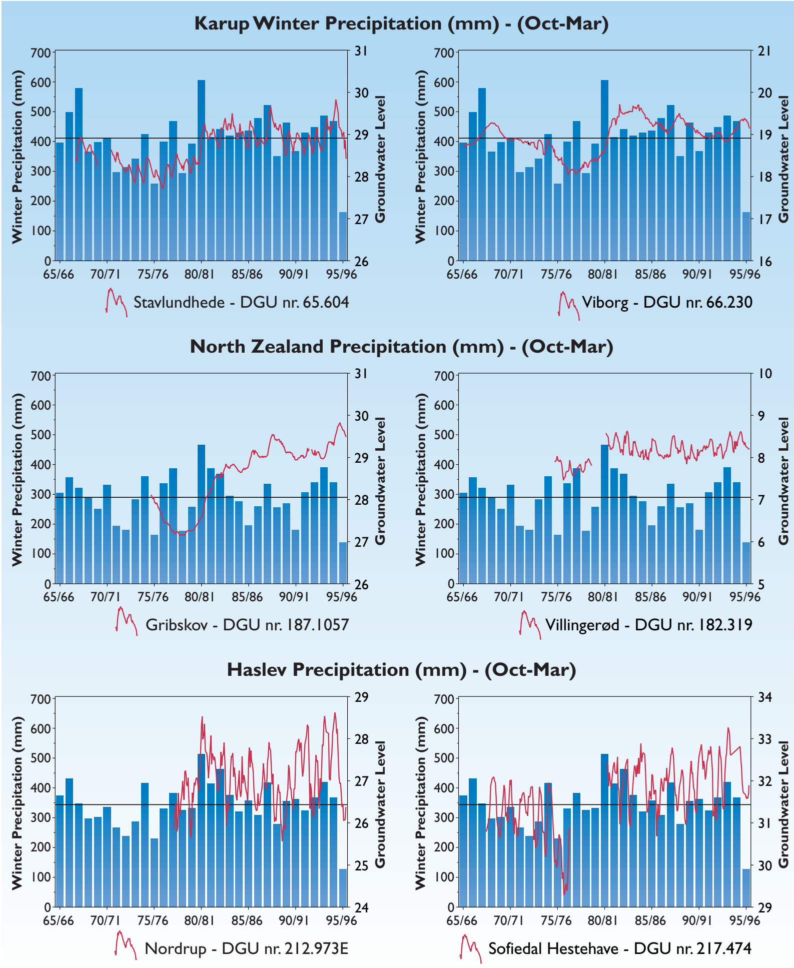


Figure 14. Regional variations in the quantity of groundwater resources. The columns show winter precipitation and the red curves represent groundwater levels. Data from the National Groundwater Level Monitoring Network provide the background for estimates of the response of the groundwater resources to climate change.

Fractures in Glacial Till and other Important Research Results

The increased focus on groundwater resources over the last years has naturally increased research efforts in this area. Government financing of research through the Strategic Environmental Research Program lead to the creation of the Groundwater Group (see box opposite page). Research results have brought forward new knowledge relevant to the planning of appropriate protection and sustainable exploitation of Denmark's groundwater in the future.

The Groundwater Group

The Groundwater Group was established under the governments Strategic Environmental Research Program. GEUS is the secretary of the group, whose members include researchers from the Technical University of Denmark (DTU), Aarhus University (ÅU), Copenhagen University (KU), The National Environmental Research Institute (DMU), Danish Institute of Plant and Soil Science (DJF), Århus County and the Danish Geotechnical Institute (GI) together with researchers from USA, Canada and Germany. The Groundwater Group was in charge of carrying out the Danish Environmental Research Program 1992-96 (SMP-1). The programs objectives were to obtain an overview of processes controlling groundwater recharge and water quality in the context of groundwater exploitation in Denmark.

The Groundwater Group is currently engaged in a new research program, Pesticides and Groundwater (SMP-96), to investigate the influence of local hydrogeologic conditions on the threat of pesticides to groundwater. In addition to the institutes listed above (excluding ÅU, GI and Århus County) members also include researchers from the Water Quality Institute (VKI) and Royal Veterinary and Agricultural University (KVL).

Some of the most noteworthy results came from field investigations which confirmed that glacial tills throughout Denmark are dissected by vertical fractures. Just a few years ago, geologist generally thought that glacial till was an effective barrier against the vertical migration of contaminants from the surface into underlying groundwater reservoirs. Now it is known that this is not correct and that the vertical migration of contaminants through glacial till can occur very quickly. The presence of fractures means that clay-rich layers even with thickness' of up to 10 m can have holes like a sieve. This realization is new (see Figure 15).

Fractures provide pathways where contaminants at the surface can quickly infiltrate with precipitation down into groundwater without the normal opportunity for attenuation and degradation. Even thick and deep lying clay layers are presumably dissected with fractures, but we do not know yet of their significance. Furthermore, the presence of fractures in contaminated clays can contribute contamination over decades to water flowing through the fractures. This new knowledge concerning the density and depth of fractures has implications for the locating of waste disposal sites, establishing protection zones for water supply wells and in estimating how long contaminated soil will impact recharge to groundwater.

But not only fractures have an influence on the infiltration of water. Results from investigations clearly show how heterogeneity in clay layers influence the transport and spreading of contaminants and how important it is to map small sand layers and holes in clay covers called "sand windows". Advanced geophysical mapping techniques can to a degree reveal numerous meaningful details concerning the geological skeleton. Deeper insight concerning infiltration and flow characteristics can only be gained by other types of measurements, among these the determination of groundwater age.

Groundwater Age Dating

In connection with the Strategic Environmental Research Program a new technique has been used to determine the age of young groundwater (groundwater less than 50 years old). The age dates provide the opportunity to clarify how fast groundwater is renewed. The age dates can also be used in estimating groundwater flow rates and to improve mathematical groundwater flow models.

The age dating method utilizes paradoxically enough the global contamination of our environment, in that it is based upon the infiltration of CFC gases from the atmosphere. CFC gases have been used in large quantities during the past 50 to 60 years in coolants, heating pipes and propellants in spray cans. The use of the gases has been greatly reduced due to the recognition that they contribute to the destruction of the ozone layer. There are different types of CFC gases and atmospheric concentrations of the different types have been calculated from the 1940's to the 1970's. Thereafter, direct measurements of the concentrations of CFC gases have been made. Concentrations of the different CFC gases in rain water is determined by the concentration in the atmosphere.

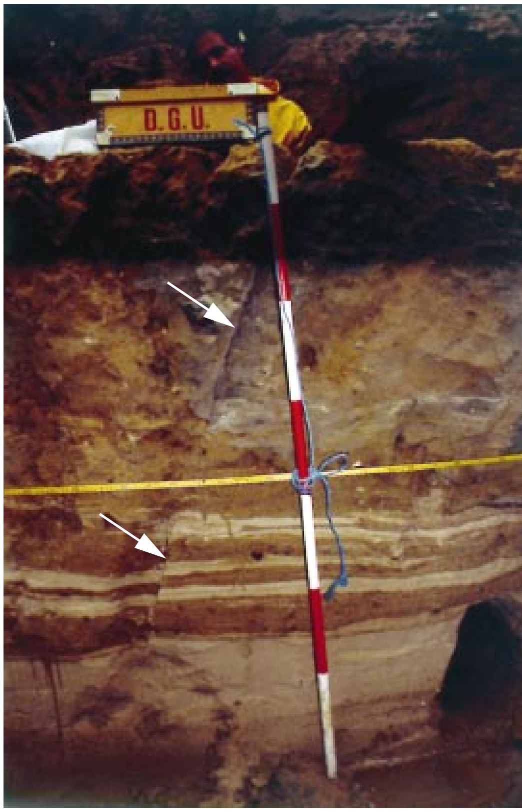


Figure 15. The arrows point to a through going fracture in clay and sand. The dark gray zone around the upper part of the fracture is downward migrating creosote.

Groundwater is often present in several water bearing layers. The shallowest layers typically contain water that has recharged the groundwater within the last decades. A considerable portion of water supply in Denmark is from small water works which abstract groundwater from shallow water bearing layers. CFC age dating is very be-

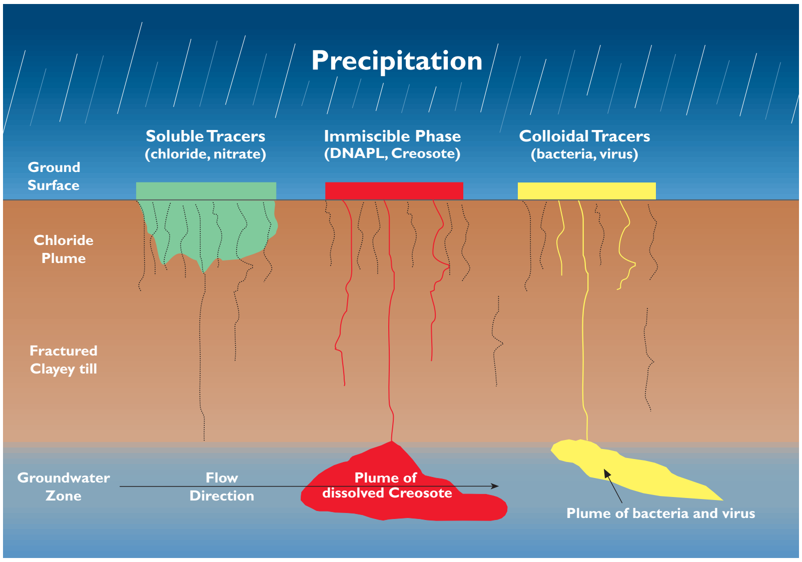


Figure 16. Fractures in glacial till increase the rate at which rain water and contaminants infiltrate to the groundwater.

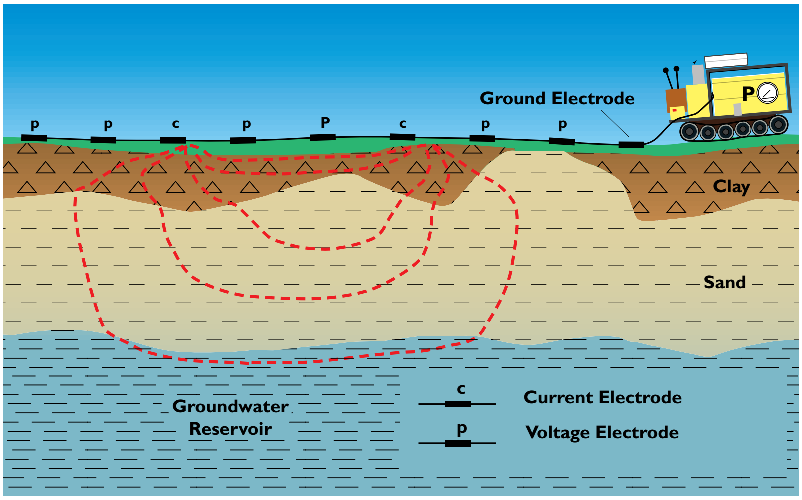


Figure 17. Differences in the electrical conductivity of earth materials provide information about the subsurface geology. The electrical conductivity of clay is greater than that of sand because the clay has a higher water content. Groundwater reservoirs can be quickly and effectively mapped using an array of surface electrodes to measure the subsurface electrical conductivity.

neficial in estimating the protection of water and if groundwater renewal rates are adequate enough to sustain consumption.

Fresh water in deep groundwater reservoirs is much older. Age date determinations by the Groundwater Group revealed that water in the investigated deep reservoirs is often greater than 2000 years old and can be as old as 7000 years. Water as old as up to approximately 35,000 years can be dated using carbon-14. This naturally occuring radioactive isotope has a half-life of 5600 years and concentrations of carbon-14 together with carbon-12 and carbon-13 show how old the groundwater is. Under the old freshwater is found even older saltwater.

Contamination Threats

Intense pumping can result in significant lowering of groundwater levels and large amounts of air are pressed in and out of the ground in response to normal changes in the atmospheric air pressure. Hereby, oxygen can be supplied to subsurface zones which have previuously been unoxidized. Oxidation can cause the weathering of pyrite, upon which nickel and sulphate are readily supplied to the groundwater. At many waterworks where large volumes of groundwater is abstracted the results have been that concentrations of sulphate and nickel exceed drinking water standards set by the environmental authorities.

Oxidation of the otherwise unoxidized zones in the subsurface can also result from irregular pumping of groundwater. Air is sucked in and out of borings when pumping wells are repeatly turned on and off, creating an oxygen supply to the groundwater reservoir. This happens for instance if a water works pumps primarily at night when electricity is cheapest. Another important realization is that groundwater levels can not fully recover after being lowered without leading to negative consequences for the water quality.

Studies investigating the distribution of contamination from landfills, bulk storage facilities and tar sites have confirmed that the substances typically will spread out in a fan-shaped plume. Continued monitoring of such plumes are important to clarify whether the contaminants are migrating towards water supply wells. It has also been assessed where and to which degree tar substances and oil products are being degraded by microorganisms in the groundwater. Studies have shown that considerable amounts of some substances are biologically degraded while other substances are not.

It is unlikely that we will ever have secured or eliminated all old landfills in Denmark. We must make priorities. Therefore it is important in every single case to clarify if the pollution threatens water supply wells. At the same time we have to know if bacteria can degrade the organic substances that leak into the groundwater. To which degree is nature capable of cleaning up after us?

It has been clarified that the concentration of substances effects the microbiol degradation. Paradoxically enough in certain cases high concentrations of contaminants are degraded more efficiently than low concentrations. This is caused by the fact that there has to be a certain amount of the substances present to create living conditions for the bacterias involved in degradation. These research results are important for securing and regulating waste disposal sites as well as selecting the location of water supply wells.

In the past years, the presence of pesticides in groundwater have been documented at several sites in Denmark. These pesticides used in insect and weed control have not been directly investigated in the research program SMP-1. But the general results reached by the Groundwater Group related to the dynamics in groundwater systems are important in relation to pesticides. The Groundwater Group is now researching pesticide pollution in a new program called Pesticides and Groundwater (SMP-96) under the Danish Environmental Research Program. These new projects will be conducted in the years leading to the turn of the century.

Water Resources and ....

Society

Of all the water on earth 2.5% is freshwater and only 0.26% of this amount or approximately 0.007% of the earths total water quality can be utilized. Based upon an average estimate, there ought to be plenty of water to meet our different needs for clean water. Unfortunately, resources are not divided equally over the earth, neither time wise or aerally. Today water shortages are a permanent problem in many areas of the world. These shortages can lead to conflicts within different countries and amongst countries sharing the resource.

Water has become an econmonic good. Control of it will be one of the key issues in the 21st Century.

In Denmark we have a very long tradition of managing our drinking water resources and in some areas we have been pioneers. Amongst others, this is the case with the Water Supply Law of 1926 (the first in worlds history!), the foundation of the Ministry of the Environment in 1971 (again the worlds first), the National Hydrogeological Mapping Program in 1976 and the National Monitoring Program in 1988. Through direct experience with the complex interaction between water and societies demands we have developed a foundation of experience valuable to national and global water resource problems. Through coordinated interaction between Danish companies and institutes we continue to further our experience. Surely, the need for this will be even greater in the future.

In order to further the progress, several institutes took the initiative to form the Danish Water Resources Committee (DVK) in 1994. The DVK was established to provide a forum that would coordinate activities, develop strategies and ensure the exchange and distribution of information within the area of water resources on the international and national level. GEUS serves as the secretary for the DVK.

The Environment

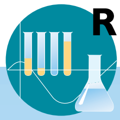
Water is the most import source for sustaining life and transporting substances, and is thus important for the condition of the environment and its development. It is important to look at the groundwater not just as an isolated system, but in connection with other aspects of the hydrologic cycle including rain,evaporation, streams and wetlands.

The interaction between climate, vegetation and soil has significant impact upon evaporation and the infiltration of water to the groundwater. Hereby, influencing the quantity and quality of groundwater resources. An increase in precipitation generally will increase the size of the water resource, but can also increase the leaching of substances to the groundwater including contaminants. In contrast, drought conditions will reduce the leaching and pollution threat, but also result in decrease groundwater levels, diminished stream flows and the drying up of wetlands.

Activities by humans further affect the water supply. This goes especially for the utilization of water for different purposes, such as drinking water, irrigation, industrial supply. In some areas groundwater abstraction is so intense that groundwater levels are permanently reduced, stream and wetlands go dry and water quality is threatened by saltwater intrusion and increasing sulfate concentrations. Activities such as drainage of wetlands and lakes, intensive use of fertilizers and pesticides in agriculture, waste storage and disposal and discharge of waste water will have a pronounced impact on water resources.

It is therefore important to view water not just as drinking water, but as an indicator of the general condition of the environment. Groundwater can collect and store the fingerprints of nature and humans. In recent years, researchers have used global environmental contaminants such as CFC gases and Tritium as useful tools for determining groundwater age dates and flow paths. Groundwater is of special interest, representing a station along the hydrologic cylcle which reflects varied and often long lasting influences; a fantastic archive to which we do not yet have all the keys.

Research



Over the years resources have been used in laboratory and field investigations to further our understanding of the processes important for the appropriate management of groundwater resources. Such studies will be needed on an ongoing basis to continuously improve our foundation of knowledge as the complexity of our water resource problems increase.

In the meantime there is a great need to integrate our knowledge and understanding in the development of operational tools so that the processes and characteristics of groundwater flow can be analyzed as part of an integrated and complex water resource system. In this context their are 3 main issues of importance for the protection and exploitation of water resources:

Groundwater Recharge, where and how is it taking place and what does it mean in light protecting groundwater and surface water?

Degree of Heterogeniety, what is its influence on the distribution of contaminants and means of clean up?

Robustness of Systems, What are the "healing" capabilities of groundwater systems and can any threshold values be found?

To address these issues, understanding of detailed processes and upscaling of parameters to an operational scale is of fundamental importance. These will also be research issues of great importance in the years to come.

Another important issue is the climate, its variation and influence on the quantity and distribution of water resources. Here we can use the knowledge gained of historical developments through long time precipitation monitoring, analysis of lake bed sediments and trace elements in the glacial ice of Greenland.

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Hans Jørgen Henriksen
Since his appointment at GEUS in 1994 Hans Jørgen Henriksen has worked with integrated water resource evaluation, primarily modelling of groundwater resource quantity, quality and protection. He is also the secretary fo the Dansih Water Resources Comittee through which he is working on coordinating international and Danish activities within water resources. He has also worked for 10 years in the private sector. At GEUS he works in the Department of Hydrology and Glaciology where he is project leader of the National Water Resource Model and the Regional Pesticide Modelling Project.

Bjarne Madsen
Bjarne Madsen is head of the Department of Hydrology and Glaciology at GEUS. He is educated as a civil engineer in hydraulics and hydrodynamics and has more than 20 years of experience working in the public and private sector in consulting, research and development projects in Denmark and abroad. Prior to his appointment at GEUS he was department head at the Water Quality Institute (VKI). He is an advisor to WMO, a member of the Danish Water Resources Committee and chairman of the board for the Groundwater Research Center at the Technical University of Denmark.

POSTBESØRGET BLAD

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The Geological Survey of Denmark and Greenland (GEUS) issues every year institutional reports.
This year the reports are:

- Annual report and Accounts 1996 (in Danish)
- Work Programme 1997 (also in Danish)
- Project Catalogue 1997, including: "Review of Activities in 1996" and "Publication Catalogue 1996" (in English)

The main part of this publication - Project Catalogue - is a listing of current projects. The intension is to inform partners, clients and others who take an interest in GEUS' activities about our range of projects, i.e. a major part our work devoted to specific scientific themes executed within agreed budgets. Several of the projects are carried out in cooperation with external partners.

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Consultant: Marianne Vasard Nielsen

Write, ring or e-mail:
GEUS
Geological Survey of
Denmark and Greenland
Thoravej 8
2400 Copenhagen NV
Denmark
Tele: +45 38 14 20 00
Fax: +45 38 14 20 50
E-mail: geus@geus.dk
Homepage: www.geus.dk

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