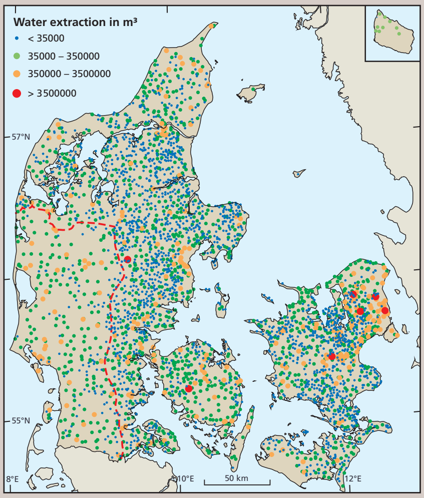
GEUS

DANISH MINISTRY OF THE ENVIRONMENT



Groundwater monitoring in Denmark

The drinking water supply in Denmark is entirely based on groundwater, and this is the reason why monitoring of groundwater is essential. 6200 public water supply wells are part of the monitoring programme.

Starting-up groundwater monitoring in 1988, an important task was to create appropriate guidelines in well drilling and design, pumping and sampling, filtering, field measurements, analyses and data reporting.

Some of the first monitoring wells were existing supply wells that were out of use, but gradually more and more wells were drilled for the purpose and they have very short screens (e.g. ½ m) to assure more precise origin of the groundwater samples.

Different pump types have been used, and the Grundfos MP1 submersible pump, developed for sampling purposes have proved very useful. In some cases other pump types are preferable however, e.g. nitrogen pressure pumps; and for CFC-dating the special water samples pumps have been developed.

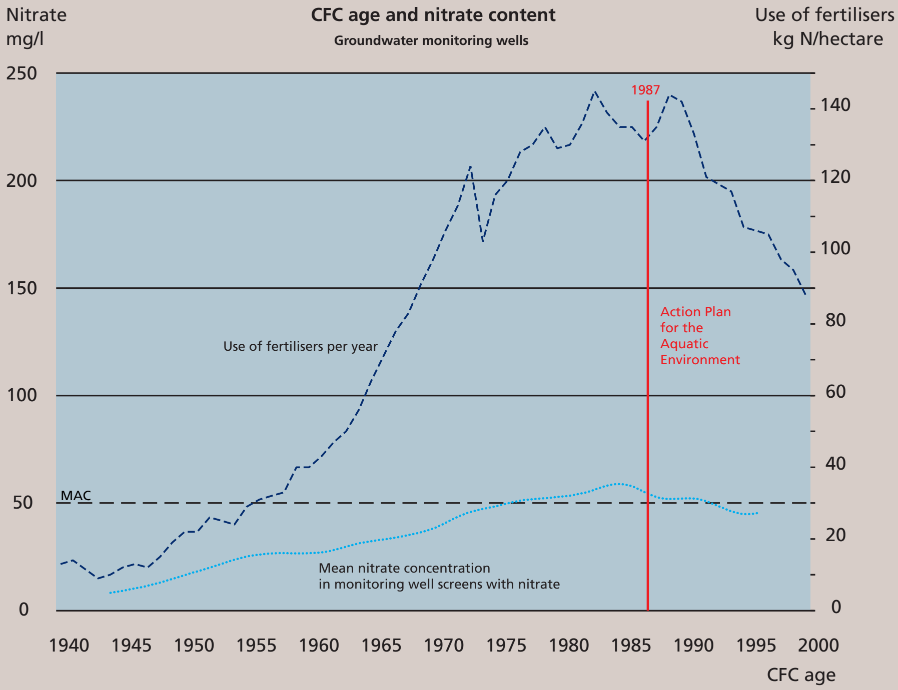
Development of standards for filtering, field measurements, and chemical analyses were developed in cooperation with the Danish Accreditation and Metrology Fund (DANAK).

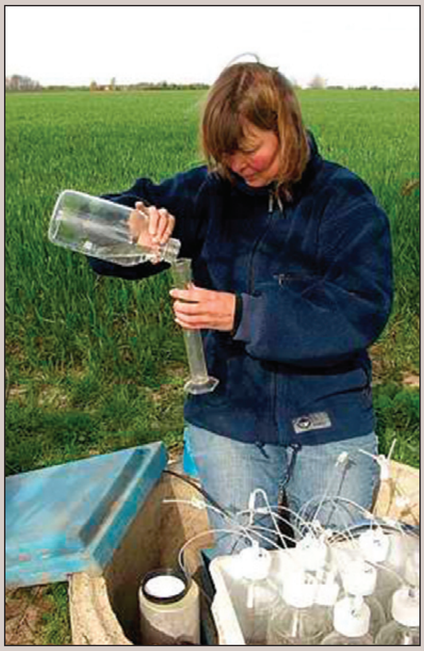
It has been important to establish a national database for wells and groundwater analyses – Jupiter at GEUS – used for update and quality control via website by all relevant users.

As the drinking water supply in Denmark is entirely based on groundwater, monitoring of the groundwater quality is extremely important to the Danish community. With more than 62% of the total land area under agricultural use, the Danish Government has determined that the entire area is vulnerable to nitrate pollution, and therefore the groundwater monitoring programme should cover the entire country.

The Danish groundwater monitoring programme comprises monitoring of water supply wells, the groundwater monitoring network and agricultural watershed monitoring. The programme is part of the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment, NOVANA.

Groundwater quality monitoring follows a detailed analytical programme of 1415 well screens from the monitoring network. This network comprises 70 catchment areas, and 100 shallow screens from five agricultural watersheds. The detailed quality monitoring includes analyses for 97 chemical elements, comprising 26 main elements, 14 heavy metals, 23 organic micro-pollutants and 34 pesticides and metabolites. Furthermore the water quality control, based on data from approximately 6200 public water supply wells, is part of the groundwater monitoring.





Nitrate is in decline

Groundwater monitoring wells give the most accurate picture of the general nitrate pollution in Danish groundwater. In 1998–2004, mean nitrate concentrations were above the MAC limit for drinking water in 16.9% of the wells, whereas about 60% had no nitrate (less than 1 mg nitrate per litre).

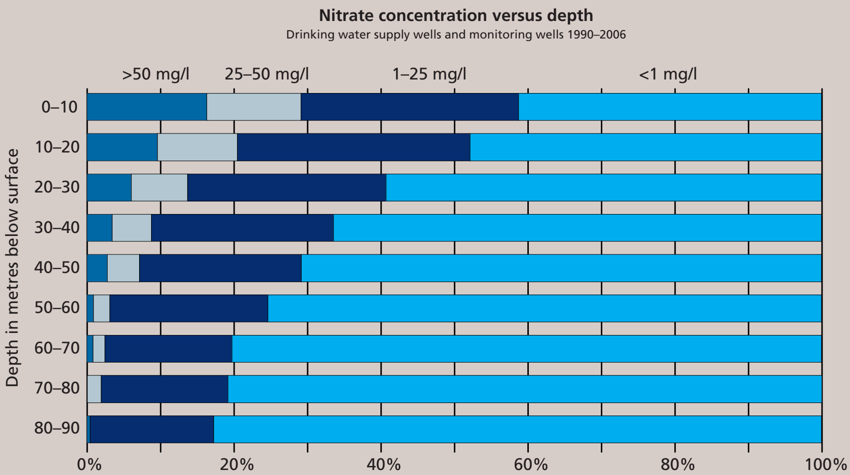
The spatial distribution of nitrate in the groundwater aquifers varies. West of the Weichselian glaciation borderline, the outwash plains are dominated by upper, unconfined aquifers overlying deeper, confined Quaternary and Miocene sands. East of the glaciation borderline the sandy meltwater deposits and the pre-Quaternary limestone aquifers are generally covered by clayey till which reduces or prevents nitrate pollution.

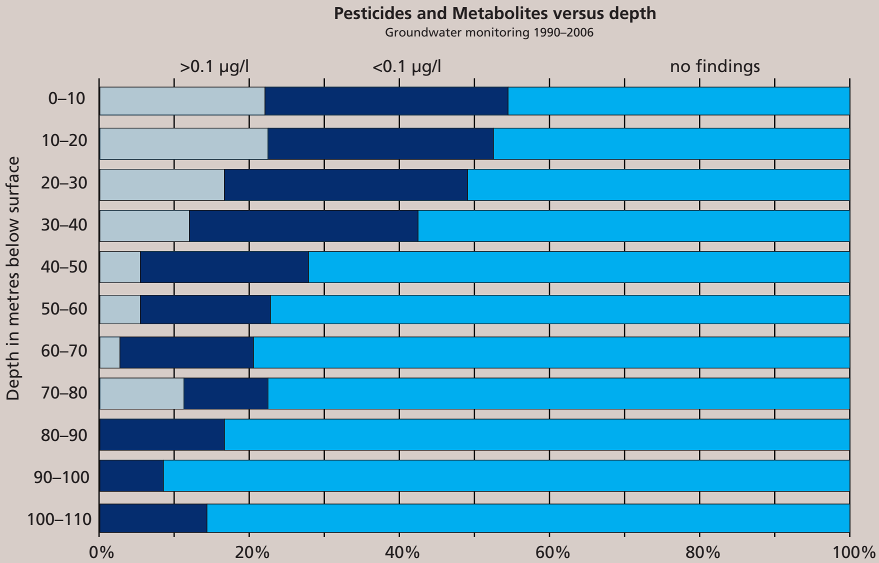
Over the past half century, the use of fertilisers in farming has intensified dramatically. Groundwater from the monitoring screens has been dated using the CFC (chlorofluorocarbon) content, and demonstrates that the highest nitrate values reflect the increase in the use of fertilisers. Continued monitoring will show whether the decrease in the use of fertilisers during the last decade will result in a decrease in the nitrate content, or whether the increasing use of manure will maintain high nitrate levels. Preliminary data suggest, however, that since 1979 farmers have adapted their spreading practice for fertilisers and manure such that nitrate pollution is now following a declining trend.

Nickel and arsenic is a problem if too much ground water has been extracted

The most widespread impact from inorganic trace elements is due to nickel derived from oxidation of pyrite, bravoite and other heavy metal bearing sulphides. Massive dissolution of sulphides occurs in areas where large-scale extraction of groundwater has caused lowering of the groundwater table, followed by an influx of oxic groundwater. During dissolution, some nickel is adsorbed by contemporaneously precipitated manganese oxides. The trapped nickel is, however, released when the groundwater table rises again, since this rise leads to reducing conditions and dissolution of the manganese oxides.

Implementation in 2001 of the EU Drinking Water Directive in Danish legislation, has led to increased concern with respect to arsenic, for which the MAC value was decreased from 50 to 5 µg/l. Nine per cent of the monitoring well screens in the groundwater





monitoring programme currently exceed 5 µg/l in all samples. The distribution of arsenic is to a large degree controlled by redox conditions, as the solubility of arsenic is about ten times higher in reducing environments compared to oxidising conditions. High arsenic concentrations are mainly found in aquifers underlying clayey sediments.

Fortunately a great part of nickel, arsenic and other trace elements precipitate together with iron and remain in the sand filters.

In coastal areas the groundwater is salty

In coastal areas, saltwater can be drawn into the aquifer when groundwater is abstracted from it. This increases the chloride content of the groundwater. In Denmark the groundwater has high chloride content in coastal areas and in areas where water is abstracted from aquifers affected by old seawater. The sea level in the waters surrounding Denmark has varied considerably through the ages. Many deep aquifers contain trapped old seawater, for example from the early Stone Age and interglacial periods.

Pesticides and metabolites in more than 25% of the wells

Analytical results from the water supply wells, the groundwater monitoring areas and the agricultural watersheds differ markedly. Only agricultural pesticides were detected in water samples collected from young groundwater in the agricultural watersheds, whereas in water samples collected in the groundwater monitoring network other pesticides, such as those used in consolidated areas like urban areas, roads or farmyards have also been found. Pesticides and their metabolites are found in more than 25% of all wells.

The most frequently found pesticide group consists of triazines and their metabolites. These compounds are commonly found in both farming and urban areas. The monitoring network demonstrates high detection rates for pesticides in the upper 40–50 m of wells tested, and a lower number of findings with increasing depth.

Drinking water from 628 dug wells and shallow drilled wells used for single private supply and minor partnership supplies (less than nine families) was investigated in a research project focusing on the youngest groundwater.

In 35% of the investigated wells, pesticides and their metabolites were recorded with values above the MAC value for drinking water (0.1 µg/L); whereas 11% of wells had more than ten times the MAC value.

The research project showed that nitrate pollution in 22% of the wells was above 50 mg per litre. The MAC level for bacteria was exceeded in 48% of the wells whereas 31% contained coliform bacteria. In total, 68% of the private supply and minor partnership supply wells delivered undrinkable water.

It is expected that restrictive rules for adoption of pesticides may effectively have reduced the risk for future pesticide pollution of groundwater.

Groundwater modelling

Evaluation of the water balance and the groundwater infiltration through hydrological modelling is a part of the NOVANA monitoring programme.

The main objective is to increase the knowledge about water balance and the sustainable groundwater resource in catchment areas, river basins and water district level. The NOVANA modelling is expected to give quality assurance on data, integration of data and feedback to inconsistencies in conceptual models and data for the water balance.

The NOVANA model gives superior knowledge about groundwater resource and degree of exploitation taking climate, land-use and abstraction strategy into account. The model will further serve minor scale models with marginal conditions.

The NOVANA model which today covers the entire country uses a horizontal discretisation of 500 x 500 m. However, the geological model and the numeric flow model are separated in the applied model systems which make it possible to operate with different detail levels.

Monitoring parameters and sampling frequencies

Main chemical elements

Field Measurements

- pH
- Conductivity
- Oxygen
- Temperature

Laboratory analyses

- Potassium
- Chloride
- Sulphate
- Nitrate
- Nitrite
- Ammonium
- Iron
- Calcium
- Bicarbonate
- Manganese
- Magnesium
- Sodium
- Total phosphor
- NVOC
- Aggressive carbon dioxide

Frequencies per year:

Field measurements: each sampling	
Wells without nitrate (<3 mg/l)	1/6
Wells with nitrate	1
Multi-screened wells	4-6
Agricultural watersheds	1/3-6

Pesticides and metabolites

1. Aminomethyl phosphoric acid (AMPA)
2. Atrazine
3. Bentazon
4. 4-CPP
5. 2,6 DCPP
6. Des-amino-diketo-metribuzine
7. Des-ethyl-atrazine
8. Des-ethyl-des-isopropyl-atrazine
9. Des-isopropyl-atrazine
10. Dichlobenil
11. 2,6-Dichlo-benzamide (BAM)
12. 2,6-Dichlor-benzoe acid
13. Dicoprop
14. Diketo-metribuzine
15. Glyphosate
16. Hexazinon
17. Mechloroprop
18. Metribuzine
19. 4-nitrophenol
20. Simazine
21. Trichloro acetic acid (TCA)
22. Des-ethyl-hydroxy-atrazine
23. Des-isopropyl-hydroxy-atrazine
24. Dide-alkyl-hydroxy-atrazien

Frequencies per year:

Wells with no findings	1/3
Shallow wells	1
Wells with findings <75% of MAC	1
Wells with higher concentrations	1
Multi-screened wells	4

Inorganic trace elements

- Aluminium (Al)
- Arsenic (As)
- Lead (Pb)
- Boron (B)
- Cadmium (Cd)
- Copper (Cu)
- Nickel
- Zink (Zn)

Frequencies per year:

Wells with low content (<75% of MAC)	1/2
Wells with higher content	1

Organic micro pollutants

Aromatic hydrocarbons

- Benzene
- Toluene
- Xylene (3 isomers)

Halogenated aliphatic hydrocarbon

- Tetrachloroethene
- Tetrachloromethane
- Trichloroethene
- Trichloromethane
- 1,1,1-Trichloroethane
- 1,2-Ethylendibromide
- Vinylchloride

Phenols and phthalates

- Phenol
- Nonylphenol
- Nonylphenolethoxylates
- Dibuthylphthalate (DBP)
- Chlorophenols
- 2,4 dichlorophenol
- 2,6 dichlorophenol
- Pentachlorophenol

Detergents

- Specific LAS

Frequencies per year:

Wells with no findings	1/6
Shallow wells	1/3
Wells with findings <75% of MAC	1/2
Wells with higher concentrations	1

References

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