6 Groundwater

(Draft translation of chapter 6 in "NOVA-2003")

The primary reason for monitoring the groundwater in Denmark is that the drinking water supply is based almost solely on groundwater. There are therefore special grounds for protecting and monitoring the groundwater (Ministry of Environment and Energy and Ministry of Agriculture and Fisheries, 1994; Danish EPA, 1998a). The quality of the groundwater is also of considerable importance for the water quality in the inland waters, however, especially in the watercourses.

Monitoring of groundwater is carried out in water supply wells and in wells established for groundwater monitoring under the Action Plan on the Aquatic Environment, as well as in wells in the agricultural monitoring catchments (Geological Survey of Denmark and Greenland, 1995 and 1998a). In addition, the groundwater is monitored in connection with investigations and monitoring of waste depositories, landfills and other soil and groundwater contamination. Finally, groundwater monitoring is also expected to be established in connection with the designation of particularly valuable water abstraction areas.

The monitoring of drinking water is carried out to control that the waterworks produce drinking water of good quality that complies with current standards for drinking water quality. The drinking water control is carried out at the waterworks, in the water mains and in consumer households. The drinking water supply is normally based on groundwater abstracted from several wells and some times also from several aquifers. Moreover, the waterworks' raw water undergoes a certain degree of treatment before being supplied to the consumers. Thus only a small part of the data from the drinking water control can be used to assess the quality of the groundwater.

6.1 Needs and objectives

6.1.1 Needs and background

The groundwater is monitored by the waterworks pursuant to the Water Supply Act and associated Statutory Order on water quality and supervision of water supply plants (Ministry of the Environment, 1985 and 1988). In addition to requiring the waterworks to control the quality of the drinking water, these also requires them to control the water from the individual water supply wells at regular intervals (normally 3–5 years) (Danish EPA, 1990a and 1997a). Similarly they are required to control water consumption and measure the height of the water table.

The groundwater is also monitored in a number of groundwater monitoring sites (GRUMO)and agricultural monitoring catchments (LOOP) - see also Chapter 5.

In the future, groundwater monitoring will probably become part of European water policy (European Commission, 1998), as well as part of a European groundwater action programme (European Commission, 1996).

The monitoring of drinking water quality and of the suitability of surface waters for the production of drinking water is carried out to ensure that summary data is available for the report to the EU on drinking water quality, implementation of the Drinking Water Directive (European Commission, 1998) and implementation of the Directive concerning the quality required of surface waters intended for the abstraction of drinking water in Member States (European Commission, 1975).

6.1.2 Objectives

The objective of groundwater monitoring in Denmark is to ensure the continual build-up of knowledge on the quality of the groundwater and its suitability for the production of drinking water. In addition, groundwater and drinking water monitoring in Denmark aims to ensure that the drinking water fulfils current health and technical quality requirements (Danish EPA, 1997a and 1998c). Finally, the monitoring aims to determine to what extent the quality of the groundwater causes pollution of watercourses and other water bodies, the quality of the groundwater being of great significance for water quality in watercourses dom.

In addition, the monitoring in the groundwater monitoring sites and agricultural monitoring catchments shall ensure knowledge about the groundwater's current state and developmental trend with a view to future adjustment of well control by the waterworks, thereby ensuring an adequate supply of groundwater of a quality suitable for the production of drinking water that will always comply with the quality requirements in force.

A knowledge of the state and developmental trend in the groundwater's chemical composition is also important in order to be able to assess the risk of corrosion in water supply plants and water mains, and for selecting new types of material for these.

The monitoring of drinking water quality is carried out at the waterworks and at the consumers in order to be able to determine whether the quality of the drinking water complies with current criteria and to determine what development has taken place in drinking water quality and what development can be expected in the future.

The objectives of the groundwater monitoring programme are to determine:

- the state and developmental trend in the parameters of groundwater state and the groundwater content of salts, heavy metals and inorganic trace elements, hazardous substances such as pesticides and other organic substances, both naturally occurring and contaminants in various types of aquifers,
- the developmental trend in groundwater quality from the subsurface aquifers to the deeper aquifers, both as a function of time and as a function of human intervention in the form of contamination and water abstraction, and
- the state and developmental trend in the size of the groundwater resource, among other things seen in the light of water abstraction.

6.2 The scientific background

The groundwater monitoring programme originated outside the Nationwide Monitoring Programme. Thus since initiation of monitoring in 1988, the groundwater monitoring programme has encompassed a broader range of parameters than the remainder of the programme. Moreover, the objective has also been broader since the use of the groundwater for the production of drinking water necessitates more detailed information about its constituents.

The discussions on groundwater monitoring have thus been going on since the beginning of the 1980s based on increasing awareness of the contamination of the groundwater with nutrients from agriculture and organic substances from various industries and service enterprises. However, actual groundwater monitoring was not established until the implementation of the so-called NPo (Nitrogen, phosphorus and organic matter) research programme, which ran from 1985 to 1990.

The intention was that 19 monitoring sites should be established called the 1st order network (Andersen, 1987) selected so as to include the most important types of aquifer found in Denmark while concomitantly ensuring that they were evenly distributed throughout the country. It was in these 19 areas established under the NPo research programme (Andersen, 1990) that the philosophy of monitoring the groundwater from the time of its formation until it reached the water supply wells was originally formulated. For economic reasons the intention was to mainly use existing wells. The intention was that the 1st order network should be operated by the State (GEUS).

In addition to the 19 monitoring sites it was intended that regional groundwater monitoring should be established encompassing approx. 150 wells in each county (Rørdam, 1987; Danish Parliament, 1987b), also called the 2nd order network, in order to obtain a better foundation for water resource planning in the counties. This model was not accepted by the Counties, however, and the final result was the adoption of a groundwater monitoring programme based on a total of approx. 75 GRUMO run by the Counties (Danish Government Budget Committee, 1987), incl. the 19 that were being established in connection with the NPo research programme.

The annexe to the Action Plan on the Aquatic Environment (Danish Parliament, 1987b) specifies that the groundwater monitoring programme also has to encompass local monitoring in the form of drinking water control and monitoring of chemical depositories, as well as a monitoring of agricultural catchments to procure data for modelling of nutrient leaching to the groundwater. The latter have subsequently been termed agricultural monitoring catchments.

In order to ensure comprehensive knowledge of the quality of the groundwater resource, well control was introduced in 1989 (Ministry of the Environment, 1988; Danish EPA, 1990a and 1997a). This ensures that the quality of the groundwater in the individual abstraction wells is regularly analysed and the results included in the groundwater monitoring programme, although with a limited number of parameters.

Prior to the establishment of groundwater monitoring, knowledge of groundwater quality was largely restricted to the groundwater's main constituents (see Table 6.2, for example), although some information was available about local contamination of groundwater with organic solvents, chlorinated hydrocarbons and occasionally pesticides such as atrazine.

The array of chemical parameters originally to be included in the groundwater monitoring programme were determined by a working group established by the Danish EPA's Water Plan Committee in 1983 and further determined by a working group established by the Danish EPA in 1985 (Danish EPA, 1987). The final array of analyses and the principles for establishing the monitoring wells for the groundwater monitoring programme were described in a memorandum adopted in 1988 (Danish EPA and Geological Survey of Denmark and Greenland, 1988). It transpired that there were rather many problems associated with the existing wells, which could be leaky or poorly constructed in various respects. A working group was therefore established to determine how the usefulness of the wells could be classified (Danish EPA, 1990b). Since then, distinction has been made between monitoring wells that are only suitable for main constituents and wells that are suitable for special analyses.

6.3 Groundwater monitoring strategy

After adoption of the Nationwide Monitoring Programme (Danish Government Budget Committee, 1987; Danish EPA, 1989) 67 groundwater monitoring sites (GRUMO) were established (Andersen, 1987) together with 6 agricultural monitoring catchments (LOOP) (Danish EPA, 1990c). At that time this was considered a sufficient and acceptable number to be able to describe the overall developmental trend in Danish groundwater, the emphasis then being on leaching from rural areas. However, not all the monitoring sites are optimally located with respect to their representativeness and function, variation in the groundwater resource, land use and the needs of society (among other things, particularly valuable water abstraction areas). Thus our knowledge of groundwater chemistry under forest and uncultivated areas is rather limited.

Expansion of the groundwater monitoring programme in connection with the designation of particularly valuable water abstraction areas (Danish EPA, 1995) is not yet possible and lies beyond the scope of the present monitoring programme, but can be expected in connection with a future revision of the monitoring programme.

In order to improve our knowledge of groundwater chemistry under uncultivated land and forest and hence begin the establishment of a sort of "baseline" for the Danish groundwater, 3 new groundwater monitoring sites will be established under forest and uncultivated land during the course of 1998. These replace 3 less well functioning sites that have been placed virtually on hold since the end of 1996. However, a very limited analysis programme for main constituents will be carried out in a small number of wells at the latter 3 sites in order to maintain some characteristic long time series showing the development in groundwater chemistry.

A fundamental principle for the selection of analysis frequencies is that the nearer a sampling screen is to the ground level, the greater the variation that can be expected during the year and hence the greater the sampling frequency required. A consequence of the groundwater monitoring hitherto undertaken is that the knowledge obtained enables the analysis frequency to be reduced for a number of substances. In connection with the present revision, these principles form the general basis for setting the analysis frequencies to be used.

The extent of the present monitoring programme is thus considered to be sufficiently comprehensive to enable an overall description of the current state and developmental trend in the quality of the Danish groundwater (see Table 6.1).

Table 6.1
Elements of the groundwater monitoring programme 1998–2003.

Monitoring elements	GRUMO	LOOP	Waterworks well control
Groundwater dating	×	×	-
Groundwater abstraction volume	-	-	×
Main constituents of groundwater	×	×	×
Heavy metals and inorganic trace elements	×	×	×
Hazardous substances (incl. pesticides and metabolites)	×	×	×
Redox wells (special wells)	×	-	-
Catchment analyses	×	×[1)]	-

1) Carried out in connection with the agricultural catchment monitoring programme.

6.4 Extent of the groundwater monitoring programme 1998–2003

The groundwater monitoring is carried out through the groundwater monitoring programme and the agricultural catchment monitoring programme, as well as through the waterworks' well control and water abstraction registration, and encompasses measurement or analysis of:

- the groundwater's age,
- the groundwater's main constituents,
- heavy metals and inorganic trace elements,
- hazardous substances,
- pesticides and metabolites, and
- water abstraction apportioned by category.

To this should be added monitoring of the height of the groundwater table, which is expected to be included in the groundwater monitoring programme at some time in the future.

The monitoring that is carried out by the waterworks encompasses analysis of water quality in the individual abstraction wells (well control), registration of the amount of water abstracted, water level readings in the abstraction wells and analysis of the quality of the drinking water in the effluent from the waterworks and in the mains supply (drinking water control). The results of the waterworks' well control and measurement of the amount of water abstracted are included as part of the groundwater monitoring programme, while water level readings in the abstraction wells in operation and drinking water control can be considered as production process monitoring.

In all cases where the analyses are undertaken at a frequency of less than once per year it is important that the analyses are evenly distributed over the 6-year programme period (see Table 6.12). In cooperation with the Counties, the Geological Survey of Denmark and Greenland has drawn up a list giving the analysis programme for each individual County (Annexe 6.1) and for each individual monitoring screen (Geological Survey of Denmark and Greenland, 1999).

6.4.1 Groundwater dating

Relative dating of the age of the groundwater has been carried out in all screens by analysis of the tritium content. It can thus be determined with reasonable certainty whether the groundwater was formed before or after approx. 1950. This dating has been used to distinguish between new and old groundwater, i.e. groundwater with a tritium content above or below 1 T.U. (Tritium Unit), respectively. However, this is inadequate for establishing a better understanding of the relationship between the time that contamination occurred and the changes that may subsequently have taken place, or to provide the necessary knowledge about the consequences of the political measures implemented since 1985.

By analysing the CFC content it is presently possible to date the oxic water formed within the last approx. 50 years with an accuracy of ±2 years (Hinsby *et al*., 1997). At present it is uncertain whether this precision can be maintained in anoxic groundwater. In order to be able to understand the distribution patterns and the developmental trend in the content of such substances as nitrate and pesticides it is important to know the groundwater's age. The groundwater from all monitoring screens with a tritium content of 1 T.U. or more is therefore being dated from its CFC content.

In addition to providing a better understanding of groundwater contamination with nitrate, etc., CFC dating will also be used to differentiate the pesticide analyses so as to avoid unnecessary analysis for pesticides that were not in use at the time the groundwater in question was formed, e.g. the "high-potency" pesticides, which have only been used in Denmark for approx. 10 years.

CFC dating is to be carried out in all groundwater monitoring screens with young groundwater in 1998, beginning with screens in the groundwater monitoring sites with a tritium content of 1–15 T.U, as well as in all screens in the agricultural monitoring catchments, beginning with the screens used to analyse for heavy metals and inorganic trace elements and hazardous substances, including pesticides and metabolites. If the economic conditions permit, dating will be repeated in the second half of the 6-year programme period.

6.4.2 Main constituents of the groundwater

The main constituents of groundwater chiefly consists of inorganic substances that are in most types of water are present in concentrations in mg/l levels. Some of these are extremely important for the quality of the water as drinking water, e.g. chloride, sulphate, nitrate and substances that determine water's hardness and the treatment that the waterworks need to undertake, e.g. its content of aggressive carbon dioxide and iron. A few of the substances are included solely to enable calculation of ion balance (analytical quality control), e.g. strontium, in cases where it occurs in high concentrations. Knowledge of the occurrence of the groundwater's main constituents is now so good that it is considered scientifically justifiable to reduce the frequency of analysis for these constituents within the groundwater monitoring programme relative to that during the programme period 1993–97.

In connection with sampling, the water samples for some of the analyses, e.g. iron and aluminium, have to be filtered to ensure that the analysis results represent the groundwater and not suspended solids such as ochre or clay. During sampling, moreover, the chemical environment in the water can change quickly, e.g. precipitation of iron or chalk through processes that consume oxygen and alter the pH. Thus wherever well construction renders it technically feasible, sampling for field measurements of pH, conductivity, oxygen content and temperature has to be carried out using an "on-line" sampler with built-in filtration. Sampling can be initiated when the chemical environment of the groundwater is constant, thereby ensuring the most accurate values for groundwater pH and oxygen content.

After 10 years of monitoring, the groundwater's main chemical constituents and their temporal and depth variation are now reasonably well documented. As mentioned above, it is therefore possible to implement a general reduction in the annual number of analyses under the groundwater monitoring programme. It has become apparent, however, that more information is needed on the temporal and depth variations in groundwater redox conditions, spatial extent of the redox zones (among others the "nitrate front") and the use of the soil layers' buffering capacity. Four so-called redox wells containing many screens are therefore to be established for frequent (6 times a year) analysis of a limited number of main constituents.

When implementing the general reduction in sampling frequency, the main chemical constituents are subdivided into two groups – a small group (the limited programme) encompassing those of the main groundwater constituents that are particularly affected by inputs from the soil surface, and a second group encompassing the other main constituents (see Table 6.2).

Table 6.2

Analysis programme for the main constituents of old and young groundwater in the groundwater monitoring sites GRUMO), in the agricultural monitoring catchments (LOOP), in redox wells and in the vicinity of Rabis Bæk stream.

Parameter	Frequency/yr					Detection limit	
Main constituents of groundwater	Old groundwater	Young groundwater	LOOP	Redox	Rabis Bæk stream		
Limited program							
Potassium	½	1	6	-	6	0.2	mg/l K
Chloride	½	1	6	6	6	1	mg/l Cl
Sulphate	½	1	6	6	6	0.5	mg/l SO_4
Nitrate	½	1	6	6	6	0.5	mg/l NO_3
Nitrite	½	1	1[1)]	6	6	0.005	mg/l NO_2
Iron	½	1	1[1)]	6	6	0.01	mg/l Fe
Manganese	½	1	1[1)]	6	6	0.005	mg/l Mn
Other main constituents							
Evaporation recidue	½	½		-	1	10	mg/l
Ammonium	½	½	1	6	6	0.01	mg/l NH_4
Calcium	½	½	1	-	1	1	mg/l Ca
Bicarbonate	½	½	1	-	1	1	mg/l HCO_3
Fluoride	½	½		-	1	0.05	mg/l F
Magnesium	½	½	1	-	1	1	mg/l Mg
Sodium	½	½	1	-	1	1	mg/l Na
Silica	½	½		-	1	1	mg/l Si
Strontium[2)]	½	½		-	1	0.1	mg/l Sr
Total nitrogen			1[3)]			0.1	mg/l N
Total phosphorus[4)]	½	½	1[3)]	-	1	0.01	mg/l P
Orthophosphate – phosphorus[5)]			1			0.005	mg/l P
NVOC[6)]	½	½	1[3)]	-	1	0.1	mg/l C
Aggressive carbon dioxide[7) 8)]	½	½	½	-	1	2	mg/l CO_2
Hydrogen sulphide[7) 9)]	½	½	½	6	6	0.02	mg/l HS
Methane[7)]	½	½	½	6	6	0.01	mg/l CH_4
Field measurements:							
pH	½	1	6	6	6	0.01	-
Conductivity	½	1	6	6	6	5	mS/l
Oxygen	½	1	6	6	6	0.1	mg/l O_2
Temperature	½	1	-	-	-	0.1	°C

1) The frequency can be reduced to 2/6 if the concentration in the two first analyses is under the detection limit, 2) At concentrations of 1 mg/l or more strontium is treated as a main constituent, 3) Supplementary analysis, 4) Analysis method: Standard DS 292: 1985, 5) Analysis method: Standard DS 291, ISO 10304-1 (EN 1189), 6) Analysis method: No current standard method is available. Oxidation and IR are determined from the CO_2 formed (Standard DS/EN 1484), 7) Analyses for aggressive carbon dioxide, methane and hydrogen sulphide are carried out only once during the period in wells in which previous repeated analyses have shown them to be absent, 8) Analysis method: Standard DS 236: 1977 and 9) Analysis method: Standard DS 278: 1976 or field analysis according to Thorning et al. (1993). See technical instruction for groundwater.

6.4.2.1 Groundwater monitoring sites (GRUMO)

In the groundwater monitoring sites, all the main constituents of groundwater are analysed once every second year in all screens. In addition, a limited number of main constituents are analysed once during the remaining years in screens containing young groundwater (Table 6.2). Young groundwater is groundwater that is classified by tritium analysis as dating from after approx. 1950 (tritium content ≥1T.U.).

6.4.2.2 Rabis Bæk monitoring site

In the 112 active screens in the groundwater monitoring site Rabis Bæk, the analysis programme for the main constituents of groundwater is carried out once yearly. In addition, a limited number of main constituents are analysed 5 times yearly in 2 screens in each well (see Table 6.2).

6.4.2.3 Redox wells

In the 4 new redox wells (approx. 60 screens), an analysis programme is conducted 6 times yearly with a limited number of parameters that are suitable for describing conditions around the redox zones in the groundwater (see Section 6.6.3 and Table 6.2).

6.4.2.4 Agricultural monitoring catchments (LOOP)

In the groundwater in the agricultural monitoring catchments the analysis programme for the main constituents is carried out once yearly in 20 screens per catchment. Analysis for potassium, chloride, sulphate, nitrate, nitrite, iron, manganese and field analyses are carried out 6 times yearly, however. The frequency for nitrite, iron and manganese can be reduced to 2/6 if the concentration in the two first analyses is below the detection limit (see Table 6.2). See also Chapter 5.

6.4.3 Heavy metals and inorganic trace elements

Heavy metals and inorganic trace elements are monitored to determine the concentration generally and in relation to various aquifer rock types and land use, as well as to demonstrate the occurrence, concentration and developmental trend of unnaturally high concentrations in the groundwater. All the selected heavy metals and inorganic trace elements have been used widely in Denmark or are naturally occurring.

The monitoring of heavy metals and inorganic trace elements hitherto undertaken has shown that approximately half of the investigated substances occur in very low concentrations, considerably below the limit value for drinking water, while the remaining substances are to a greater or lesser extent found in concentrations near or above the limit value for drinking water. It is therefore important to analyse these substances more frequently, especially in the young groundwater, among other reasons in order to be able to demonstrate relationships and developmental trends. On the other hand, only limited monitoring is carried out on heavy metals and inorganic trace elements that do not appear to be affected by human activity or which do not occur in concentrations near the limit value for drinking water. Nevertheless, sufficient monitoring activity is maintained to reveal any changes that might occur in the previous pattern (see Table 6.3).

At the same time, it is considered necessary – at least for a period – to extend the number of parameters in order to have the necessary reference material in respect of the “List II” substances in the EU groundwater Directive (80/68/EØF). From 1998 onwards the programme will therefore be extended to encompass monitoring of the substances antimony, silver, thallium and tin as these have been in common and widespread use in Denmark: antimony, especially in shot pellets, silver in photographic chemicals, thallium in rat poison and tin in solder, etc.

Some of the heavy metals have been applied to fields and forests in commercial fertilizer, natural fertilizer or sewage sludge, e.g. cadmium, copper, nickel, zinc and lead.

Analysis for heavy metals and inorganic trace elements, which has been extended to encompass four new substances, is carried out once during the 6-year programme period supplemented with one extra analysis for the four new substances during the same period. In addition, one single annual analysis is carried out for a limited number of heavy metals and inorganic trace elements in young groundwater (Table 6.3). The limited programme encompasses heavy metals and inorganic trace elements considered to be input to soil surface in significant amounts.

The agricultural monitoring catchments are equipped with groundwater screens immediately below the root zone and will be able to reveal possible contamination with the main constituents of groundwater as well as with heavy metals, inorganic trace elements and hazardous substances within a few years after their application to the soil surface. In the agricultural monitoring catchments, moreover, inputs of fertilizers and pesticides have been recorded at field level during the previous monitoring period (1992–97). This is of significance for an understanding of the transport of contaminants from infiltration sites to the wells.

In order to improve understanding of the possible future consequences for the groundwater, the analysis programme for the main constituents of groundwater in the agricultural monitoring catchments is supplemented with a limited programme encompassing heavy metals and inorganic trace elements believed to have been input from the soil surface, as well as hazardous substances, pesticides and metabolites. In the 5 agricultural monitoring catchments, analysis for heavy metals and inorganic trace elements is carried out 4 times yearly in 10 screens and every third year in another 30 screens (see Table 6.3).

In order to ensure the best possible conditions for demonstrating chemical relationships, the samples for the main constituents (Table 6.2) and those for the heavy metals and inorganic trace elements (Table 6.3) should be collected simultaneously.

Table 6.3
Analysis programme for heavy metals and inorganic trace elements in the groundwater.

Parameter	Frequency/yr				Detection limit	
Heavy metals and inorganic trace elements	Groundwater		LOOP			
	Old	Young	10 screens	30 screens		
Limited programme:						
Aluminium (Al)	1/6	1	4	2/6	0.07	µg/l
Arsenic (As)	1/6	1	4	2/6	0.03	µg/l
Barium (Ba)	1/6	1	4	2/6	1	µg/l
Lead (Pb)	1/6	1	4	2/6	0.025	µg/l
Cadmium (Cd)	1/6	1	4	2/6	0.004	µg/l
Copper (Cu)	1/6	1	4	2/6	0.04	µg/l
Nickel (Ni)	1/6	1	4	2/6	0.03	µg/l
Selenium (Se)	1/6	1	4	2/6	0.05	µg/l
Zinc (Zn)	1/6	1	4	2/6	0.5	µg/l
Other heavy metals and inorganic trace elements:						
Antimony (Sb)	2/6	2/6	-	-	0.2	µg/l
Boron (B)	1/6	1/6	-	-	10	µg/l
Bromide (Br^{-})	1/6	1/6	-	-	10	µg/l
Cyanide (CN^{-})	1/6	1/6	-	-	1	µg/l
Iodide (I^{-})	1/6	1/6	-	-	2	µg/l
Chromium (Cr)	1/6	1/6	-	-	0.04	µg/l
Mercury (Hg)	1/6	1/6	-	-	0.0005	µg/l
Lithium (Li)	1/6	1/6	-	-	0.5	µg/l
Molybdenum (Mo)	1/6	1/6	-	-	0.1	µg/l
Strontium (Sr)	1/6	1/6	-	-	1	µg/l
Silver (Ag)	2/6	2/6	-	-	0.1	µg/l
Thallium (Th)	2/6	2/6	-	-	0.4	µg/l
Tin (Sn)	2/6	2/6	-	-	0.1	µg/l
Vanadium (V)	1/6	1/6	-	-	0.5	µg/l

6.4.4. Hazardous substances

Among the hazardous substances, methylphenols, dimethylphenols and GC/MS screening have been deleted from the monitoring programme for the time being, partly because they have very rarely been detected, and partly because for all intents and purposes, GC/MS screening has not been carried out by the Counties in connection with the demonstration of high levels of VOX. Because of this together with difficulties in interpreting the results, the combined parameters for the organic halogens (AOX and VOX) have also been deleted.

The programme for the agricultural monitoring catchments has been extended to also encompass hazardous substances since certain substances are expected to be input with manure slurry, sewage sludge or in some other way (Table 6.4).

Aromatic hydrocarbons and halogenated aliphatic hydrocarbons are substances that have been frequently used throughout Denmark, in private homes and especially in the dye, paint and metal-finishing industries and in dry-cleaning establishments. The same applies to phenols and certain chlorophenols, while other chlorophenols are considered to be metabolites of pesticides.

Benzene and methyl tertiary-butyl ether (MTBE) are constituents of petrol. The programme has been extended to encompass 3 new parameters: vinyl chloride, which is a degradation product of halogenated aliphatic hydrocarbons, MTBE, which has been used as a petrol additive instead of lead since the 1980s, and ethylene dibromide, which is a soil disinfectant used in greenhouses.

6.4.4.1 Aromatic hydrocarbons and halogenated aliphatic hydrocarbons

Aromatic hydrocarbons and halogenated aliphatic hydrocarbons are only occasionally detected in the monitoring wells, which are mainly situated in the rural areas. The analysis frequency has therefore been reduced from every second year to every third year in screens in rural areas. This is concomitantly to be accompanied by a differentiation such that the frequency is increased to once yearly in screens in which hazardous substances have been detected. Analysis for aromatic hydrocarbons and halogenated aliphatic hydrocarbons is normally carried out twice over a 6-year period in the groundwater monitoring sites (Table 6.4).

Table 6.4

Analysis programme for hazardous substances etc. in the groundwater (young and old) and in agricultural monitoring catchments (LOOP). For both scientific and economic reasons, analysis for chlorophenols, detergents, phenol compounds and plasticizers is carried out concomitantly with the analyses for pesticides.

Parameter	Frequency/yr			Detection limit
	Groundwater		Agricultural monitoring catchments	
	Young	Old		
Aromatic hydrocarbons:				
Benzene	2/6	2/6	2/6	0.04 µg/l
Naphthalene	2/6	2/6	2/6	0.02 µg/l
Toluene	2/6	2/6	2/6	0.04 µg/l
Xylenes (p-xylene, m-xylene and o-xylene)	2/6	2/6	2/6	0.02 µg/l
Phenols:				
Nonylphenol	-	2/6	2/6	0.05 µg/l
Nonylphenolethoxylates (Mono- and diethoxylates)	-	2/6	2/6	0.05 µg/l
Phenol	-	2/6	2/6	0.03 µg/l
Halogenated aliphatic hydrocarbons:				
Tetrachloroethylene	2/6	2/6	-	0.02 µg/l
Tetrachloromethane	2/6	2/6	-	0.03 µg/l
Trichloroethylene	2/6	2/6	-	0.02 µg/l
Trichloromethane (chloroform)	2/6	2/6	-	0.02 µg/l
1,1,1-trichloroethane	2/6	2/6	-	0.02 µg/l
1,2-dibromomethane	2/6	2/6	-	0.02 µg/
Vinyl chloride	2/6	2/6	-	0.05 µg/l
Chlorophenols:				
2,4-dichlorophenol	2/6	1	-	0.03 µg/l
2,4-dichlorophenol, 20/40 selected screens	-	4	4	0.03 µg/l
2,6-dichlorophenol	2/6	1	-	0.03 µg/l
2,6-dichlorophenol, 20/40 selected screens	-	4	4	0.03 µg/l
Pentachlorophenol	2/6	1	-	0.02 µg/l
Pentachlorophenol, 20/40 selected screens	-	4	4	0.02 µg/l
Plasticizers (phthalates):				
Dibutylphthalates (DBP)	-	2/6	2/6	0.5 µg/l
Anionic detergents:				
SUM parameter (lauryl-alcohol-sulphate)	-	2/6	2/6	3 µg/l
Cationic detergents:				
DTDMAC	-	2/6	2/6	not set µg/l
Ether:				
Methyl tertiary-butyl ether (MTBE)	-	2/6	-	1 µg/l

6.4.4.2 Ethers

Analysis for MTBE is also carried out twice over a 6-year period, but will only be included in the analysis programme for groundwater monitoring site screens in which the groundwater has been formed in 1985 or later (determined by CFC dating). This is estimated to involve approx. 100 screens evenly distributed throughout the country.

6.4.4.3 Chlorophenols

Chlorophenols have only rarely been detected and the number of parameters is therefore limited. As chlorophenols can be pesticide metabolites, the analyses should in future be carried out together with the pesticide analyses. Analysis for chlorophenols are carried out together with analyses for pesticides and metabolites in both the groundwater monitoring sites and in the agricultural monitoring catchments (see below), although analysis for chlorophenols is carried out every third year in old groundwater.

6.4.4.4 Detergents, phenols and plasticizers

Analysis of detergents has hitherto been restricted to the anionic detergents. In view of the widespread use of cationic detergents, phenols (nonylphenols) and plasticizers, and their resultant presence in livestock manure, wastewater, sludge, etc., the programme has been extended to also include analysis for these substances. In the groundwater monitoring sites and agricultural monitoring catchments, analysis for detergents, nonylphenols, phenol and plasticizers is carried out every third year in young groundwater (Table 6.4).

6.4.4.5 Agricultural monitoring catchments

In the agricultural monitoring catchments, analysis for hazardous substances (aromatic hydrocarbons, phenols, detergents and plasticizers) is carried out twice during a 6-year period. Analysis for chlorophenols is carried out together with the analyses for pesticides and metabolites.

6.4.4.6 Pesticides

Pesticide monitoring has hitherto encompassed 8 substances, all of which are detected with varying concentrations and frequency. During the preceding programme period, numerous more comprehensive investigations of the pesticide content of groundwater have been carried out by the Counties and waterworks, leading to the detection of approx. 35 different pesticides and metabolites in the groundwater. It has therefore been necessary to considerably extend the number of pesticides and metabolites included in the groundwater monitoring. The analysis frequency has been kept the same for the young groundwater, while pesticide analyses in the old groundwater formed before approx. 1950 will be restricted to one time during the programme period.

Several criteria have been used to select the pesticides to be monitored, not least including high levels of total consumption, widespread use, long period of use and water solubility. Metabolites that are known or suspected of being very stable under the chemical conditions pertaining in groundwater are also included. Finally, emphasis has been placed on substances that have been detected in Danish or foreign groundwater and surface water. Over half of the selected pesticides and metabolites have previously been detected. A few of the substances have only been in use since the mid 1980s. These substances will only be included in the analysis programme in wells with groundwater formed in 1985 or later (determined by CFC dating).

It is still not possible to provide a clear description of annual variation in the groundwater content of pesticides. Monitoring of the pesticide content will therefore continue involving frequent analyses (4 times yearly) in 14 selected screens in the groundwater monitoring sites and approx. 40 selected screens in the agricultural monitoring catchments to determine the variation (see Table 6.5).

Analysis for pesticides and metabolites is carried out once yearly in young groundwater (Table 6.4). The reason for the relatively frequent analysis for pesticides in young groundwater is to ensure that reliable material will be available within the space of 2–3 years. During the programme period, pesticides are to be analysed once in old groundwater (see Annexe 6.3). A few of the substances have only been in use since the mid 1980s and hence are only included in the pesticide analysis programme for wells with groundwater formed in 1985 or later (determined by CFC dating). It should be noted that chlorophenols (Table 6.4) must be analysed in the same screens and with the same frequency as pesticides and metabolites.

Table 6.5
Analysis programme for pesticides and metabolites in groundwater monitoring sites (GRUMO) and agricultural monitoring catchments (LOOP).

Parameter	Frequency/yr				Detection limit
Pesticides and metabolites	GRUMO		Selected screens		
	Young	Old	14 in GRUMO	Approx. 40 in LOOP	
Aminomethylphosphonic acid (AMPA)	1	1/6	4	4	0.01 µg/l
Atrazine	1	1/6	4	4	0.01 µg/l
Bentazone	1	1/6	4	4	0.01 µg/l
Bromoxynil	1	1/6	4	4	0.01 µg/l
Carbofuran	1	1/6	4	4	0.01 µg/l
Chloridazon	1	1/6	4	4	0.01 µg/l
Chlorsulfuron	1	1/6	4	4	0.01 µg/l
Cyanazin	1	1/6	4	4	0.01 µg/l
2,4-D	1	1/6	4	4	0.01 µg/l
Dalapon	1	1/6	4	4	0.01 µg/l
Desethylatrazine	1	1/6	4	4	0.01 µg/l
Desethyldesisopropylatrazine	1	1/6	4	4	0.01 µg/l
Desethylterbutylazine	1	1/6	4	4	0.01 µg/l
Desisopropylatrazine	1	1/6	4	4	0.01 µg/l
Dichlobenil	1	1/6	4	4	0.01 µg/l
2,6-dichlobenzamid (BAM)	1	1/6	4	4	0.01 µg/l
Dichlorprop	1	1/6	4	4	0.01 µg/l
Dimethoate	1	1/6	4	4	0.01 µg/l
Dinoseb	1	1/6	4	4	0.01 µg/l
Diuron	1	1/6	4	4	0.01 µg/l
DNOC	1	1/6	4	4	0.01 µg/l
Ethofumesate	1	1/6	4	4	0.01 µg/l
Ethylenthiourea (ETU)	1	1/6	4	4	0.01 µg/l
Fenpropimorph	1	1/6	4	4	0.01 µg/l
Glyphosate	1	1/6	4	4	0.01 µg/l
Hexazinon	1	1/6	4	4	0.01 µg/l
Hydroxyatrazine	1	1/6	4	4	0.01 µg/l
3-hydroxycarbofuran	1	1/6	4	4	0.01 µg/l
Hydroxysimazine	1	1/6	4	4	0.01 µg/l
Ioxynil	1	1/6	4	4	0.01 µg/l
Isoproturon	1	1/6	4	4	0.01 µg/l
Lenacil	1	1/6	4	4	0.01 µg/l
Maleinhydrazide	1	1/6	4	4	0.01 µg/l
MCPA	1	1/6	4	4	0.01 µg/l
Mechlorprop	1	1/6	4	4	0.01 µg/l
Metamitron	1	1/6	4	4	0.01 µg/l
Metribuzin	1	1/6	4	4	0.01 µg/l
Metsulfuron methyl	1	1/6	4	4	0.01 µg/l
4-nitrophenol	1	1/6	4	4	0.01 µg/l
Pendimethalin	1	1/6	4	4	0.01 µg/l
Pirimicarb	1	1/6	4	4	0.01 µg/l
Propiconazole	1	1/6	4	4	0.01 µg/l
Simazine	1	1/6	4	4	0.01 µg/l
Terbuthylazine	1	1/6	4	4	0.01 µg/l
Trichloroacetic acid (TCA)	1	1/6	4	4	0.01 µg/l

Based on the data on pesticides collected in the groundwater monitoring and general improvements in our understanding of the occurrence of pesticides in groundwater it may become necessary to modify the analysis programme for pesticides during the programme period.

Chlorsulfuron, ethofumesate, fenpropimorph and metsulfuron methyl are only analysed for in groundwater formed after 1984 (determined by CFC dating). Correspondingly, ETU is only analysed for in the sites where potatoes, peas or fruit have been grown within the past 30–40 years. Finally, the substances hydroxysimazine, thiram and trichloroacetic acid (TCA) cannot be analysed for in 1999 as suitable laboratories have not yet been assigned (see Table 6.5).

6.4.5 Redox wells

In each of 4 rural aquifers a well containing 15 small screens is to be established for monitoring the stability of and variation in the redox zones. The screens will be placed at very close intervals above each other to enable sampling at well-defined levels in the aquifers. The wells in the Rabis Bæk monitoring site will form part of this monitoring.

The analysis programme in the 4 redox wells encompasses ammonium, chloride, sulphate, nitrate, nitrite, iron, manganese, hydrogen sulphide and methane, as well as field measurements of pH, conductivity, oxygen and possibly also Eh (reduction potential). Ammonium, hydrogen sulphide and methane will initially be analysed for in all screens, but thereafter only in the screens in which they can be expected to occur (Table 6.2). The analysis frequency is 6 times yearly in all screens.

6.4.6 Water abstraction

In order to be able to assess the development in exploitation of the groundwater resource, total water abstraction volume is calculated once yearly based on the abstraction data. The calculation has to be subdivided by the categories public water supplies, private common water supplies, other common water supplies, institutions with separate water abstraction, enterprises with separate water abstraction, and water abstraction for field watering, market gardens, freshwater fish farms, hotels and camping sites, etc. The calculation should be supplemented with a qualified estimate of individual abstraction, small non-common waterworks and other abstraction, including wells used for remedial abstraction of groundwater at contaminated sites.

6.4.7 Modelling

In order to be able to assess groundwater recharge and the movement patterns of contaminated groundwater in the individual groundwater monitoring sites it is intended that the Counties should establish geological and mathematical/numeric models for the individual groundwater monitoring sites during the course of the programme period. As a first step, geological (conceptual) models have been established in 1–2 groundwater monitoring sites in each county. The first mathematical/numerical models are expected to be established in the beginning of the year 2000.

6.4.8 Catchment analyses

In order to improve our understanding of the sources and processes that determine groundwater quality in the individual groundwater monitoring sites, the land use survey is to be regularly updated. As far as possible the new land use charts prepared for the Ministry of Food, Agriculture and Fisheries should be incorporated (Buch, 1996).

6.5 Location of the groundwater monitoring 1998–2003

The direct consequence of the adoption of the Nationwide Monitoring Programme was the establishment of 67 groundwater monitoring sites and 6 agricultural monitoring catchments. With the present revision of the programme the number of agricultural monitoring catchments with water chemistry monitoring has been reduced to 5 in that monitoring of water chemistry has ceased in the agricultural monitoring catchment Barslund Bæk.

Further groundwater monitoring is carried out at the approx. 2,900 Danish public water supplies encompassing approx. 10,000 wells. This monitoring is partly controlled by the Water

Supply Act and associated Standing Orders and Guidelines, and partly by municipal council decisions.

Both types of groundwater monitoring are included in the comprehensive databases maintained by the Counties and the Geological Survey of Denmark and Greenland and they are reported together each 1 June by the Counties and each 1 December by the Geological Survey of Denmark and Greenland.

6.5.1 Groundwater monitoring sites (GRUMO)

The groundwater monitoring encompass 67 groundwater monitoring sites (GRUMO) that are relatively evenly distributed throughout the country with respect to geology, hydrology, land use, etc. As far as possible the groundwater monitoring sites within each county are also representatively distributed (see Table 6.6 and Figure 6.1).

Of the 67 groundwater monitoring sites, 3 sites have largely been placed on hold (in parentheses in Table 6.6) and replaced by 3 others that will become fully operational in 1999. The abstraction well at the new site Klosterhede in Ringkøbing County will not be operational until the year 2000, however. The Jyderup Skov site in Vestsjælland County is expected to become fully operational by 1 January 2001. To the extent that wells in the new sites become usable earlier, they will be included in the programme on a normal basis.

As time series reaching back to 1990 are available for the main constituents of groundwater in some of the screens in the 3 groundwater monitoring sites that have been placed on hold, a limited analysis programme for the main constituents of groundwater will continue to be carried out once yearly in these screens for the sake of continuity.

The groundwater monitoring site Holeby in Storstrøm County has not functioned satisfactorily and will be extensively rebuilt during the course of 1998–99.

The location of the groundwater monitoring sites and agricultural monitoring catchments is shown in Figure 6.1. The names and the GRUMO and LOOP numbers are listed by county in Table 6.6.

Table 6.6
Groundwater monitoring sites and agricultural monitoring catchments ordered by county and with GRUMO and LOOP numbers

Copenhagen/Frederiksberg Municipality:		Storstrøm County:		Ribe County:		Aarhus County:	
13.11	Frederiksberg	35.01	Holeby	55.01	Grindsted	70.01	Havdal
Copenhagen County:		35.03	Hjelmsølille	55.11	Bramming	70.02	Kasted
15.11	Søndersø	35.11	Vesterborg	55.12	Ølgod	70.11	Nordsamsø
15.12	Ishøj	35.12	Sibirien	55.13	Forumlund	70.12	Fillerup
15.13	Gladsaxe	35.13	Store Heddinge	55.14	Vorbasse	70.13	Hvinningdal
Frederiksborg County:		LOOP 1	Highvads Rende	Vejle County:		70.14	Homå
20.01	Endrup	Bornholm County:		60.01	Egebjerg	Viborg County:	
20.11	Skuldelev	40.01	Smålyng	60.11	Tyregod	76.01	Rabis Bæk
20.12	Asserbo	Funen County:		60.12	Trudsbro	76.11	Viborg Nord
20.13	Attemose	42.01	Nyborg	60.13	Follerup	76.12	Skive
20.14	Espergærde	42.02	Borreby	60.14	Ejstrupholm	76.13	Nykøbing M.
Roskilde County:		42.11	Svendborg	Ringkøbing County:		76.14	Thisted
25.01	Torkilstrup	42.12	Nørre Søby	(65.01	Herning)	Nordjylland County:	
25.02	Brokilde	42.13	Harndrup	65.11	Brande	80.01	Tornby
25.11	Asemose	42.14	Jullerup	65.12	Haderup	80.02	Råkilde
25.12	Osted	LOOP 4	Lillebæk	65.13	Herborg	80.11	Drastrup
Vestsjælland County:		Sønderjylland County:		65.14	Finderup	80.12	Skerping
30.01	Holbæk	(50.01	Abild)	65.15	Klosterhede	80.13	Albæk
(30.11	Munke Bjergby)	50.02	Mjang Dam	Vejle County/Aarhus: County		80.14	Gislum
30.12	Store Fuglede	50.11	Bedsted			LOOP 2	Odderbæk
30.13	Nykøbing Sj.	50.12	Rødding	LOOP 3	Horndrup Bæk		
30.14	Eggerslevmagle	50.13	Christiansfeld				
30.15	Jyderup Skov	50.14	Frøslev				
		LOOP 6	Bolbro Bæk				

Figure 6.1
Groundwater monitoring sites (GRUMO) (·) and agricultural monitoring catchments (LOOP), level 3 + 4 (○) in Denmark 1998–2003. The groundwater monitoring sites Munke Bjergby, Abild and Herning have been placed on hold since the end of 1996 (shown in parentheses) except that a very limited programme is being continued in a small number of screens in the 3 sites. These sites are being replaced by 3 new groundwater monitoring sites, Jyderup Skov, Frøslev and Klosterhede.

In the groundwater monitoring sites, monitoring of the groundwater in the smaller subsurface aquifers is carried out using so-called point-monitoring screens, while that in the larger deeper-lying aquifers is carried out using on-line monitoring screens. In addition the groundwater is normally monitored once yearly in a single abstraction well – the volume-monitoring well in the large aquifer, the main aquifer – in each groundwater monitoring site (Figure 6.2). In the agricultural monitoring catchments it is the newly formed uppermost groundwater that is monitored.

With the increase in the number of wells over the period 1993–97 a groundwater monitoring site will normally consist of a single abstraction well and approx. 16 monitoring screens located upstream of the abstraction well so as to enable monitoring of the quality of both the water in the main aquifer and that in the subsurface secondary aquifers. At the end of 1997 the groundwater monitoring sites included 1,039 screens. To this should be added a further 112 screens in the Rabis Bæk site that are only used for analysis of the groundwater's main constituents, as well as approx. 60 screens in the 4 new redox wells, giving a total of 1,211 screens. This figure also includes a standard figure of 51 screens in the three new groundwater monitoring sites and the 24 screens in the 3 monitoring sites placed on hold, where monitoring will be continued using a limited analysis programme (see tables 6.7, 6.8 and 6.9).

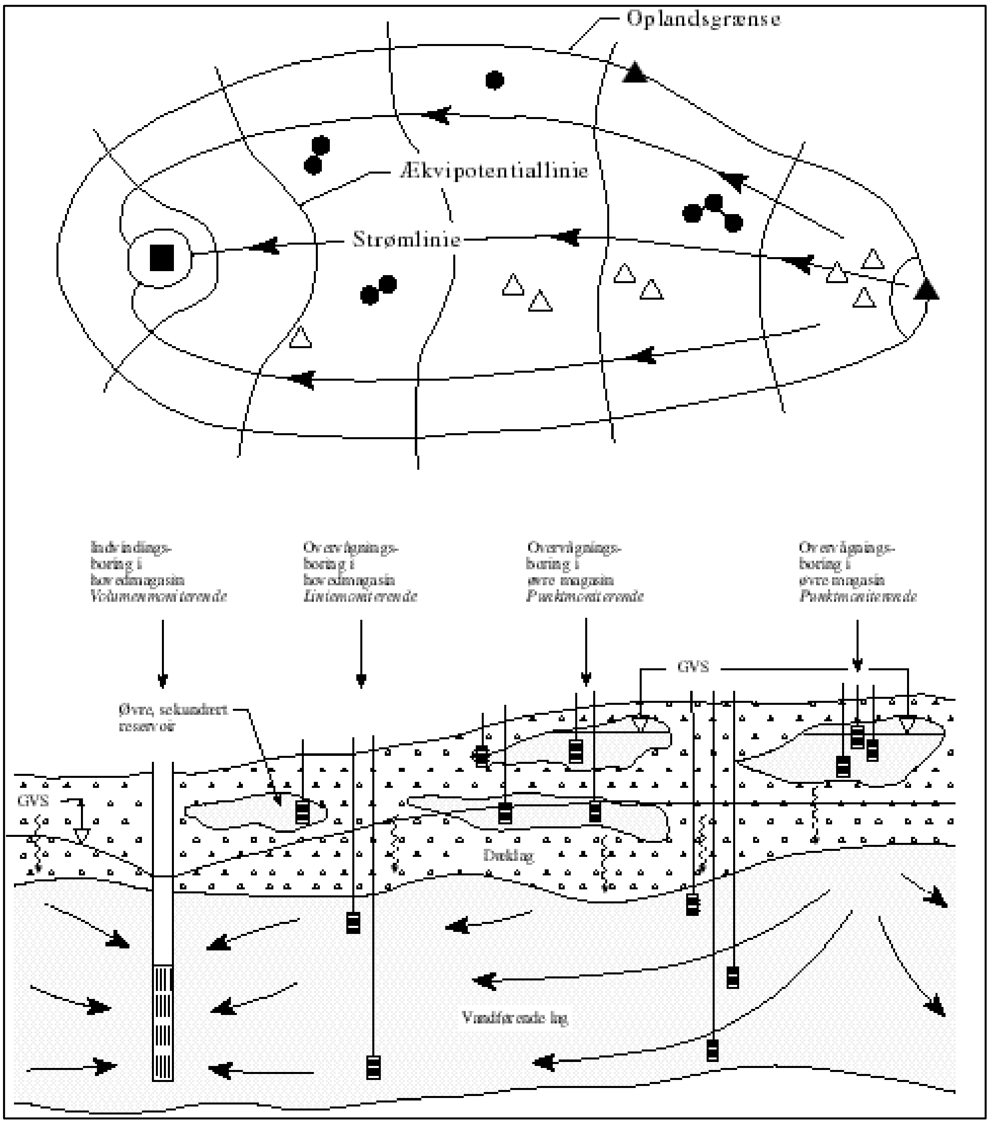

Figure 6.2
Schematic diagram indicating the location of monitoring screens in a monitoring site (adapted from Andersen, 1987).

Of the total number of screens, the abstraction well and approx. 13 monitoring screens in each groundwater monitoring site have to be able to be used for special analyses, i.e. heavy metals and inorganic trace elements, hazardous substances, pesticides and metabolites, etc. At the end of 1997, 876 screens were suitable for special analyses. To this should be added the approx. 42 screens in the 3 new monitoring sites.

The groundwater potential is measured in the individual monitoring wells wherever technically feasible. If the seasonal variation needs to be determined, for example in connection with modelling of the individual monitoring sites, measurement of the groundwater potential should preferably be carried out 4–6 times annually per well, evenly distributed throughout the year.

6.5.2 Monitoring in the Rabis Bæk site

Groundwater monitoring in the Rabis Bæk site started in the 1980s under the NPo research programme. The monitoring is primarily intended to describe the developmental trend in the main constituents of the groundwater in the upper unenclosed aquifers. It is expected that the monitoring in the Rabis Bæk site will complement the monitoring in the 4 redox wells. See Table 6.8.

6.5.3 Monitoring in redox wells

The 4 redox wells have been sited and established by the Counties in agreement with the Topic Centre. The wells do not have to be placed in one of the existing monitoring sites. There is one redox well in each of the 4 counties: Storstrøm County (Sibirien), Ribe County (Grindsted), Aarhus County (Kasted) and Nordjylland County (Albæk). See Table 6.9.

Table 6.7

Groundwater analysis programme for the groundwater monitoring sites (GRUMO) during the programme period 1998–2003, indicating analysis type, number of screens and analysis frequency and selection principle.

	Number of screens	Analysis frequency/yr	Selection principle
Groundwater age:			
CFC dating	843	1/6	Young g.w.
Main constituents:			
Limited programme	1025	0.5	All screens
Limited programme	829	0.5	Young g.w.
Limited programme, frequent analysis	14	4	20 in alt
Aggressive carbon dioxide	703	0.5	Data-dependent
Methane	740	0.5	Data-dependent
Hydrogen sulphide	363	0.5	Data-dependent
Other main constituents	1015	0.5	All screens
Field measurements	1039	Every time	All screens
Heavy metals and inorganic trace elements:			
Limited programme	735	1	Young g.w. special
Limited programme	183	1/6	Old special
New parameters	918	2/6	All special
Other heavy metals and inorganic trace elements	918	1/6	All special
Pesticides, metabolites and chlorophenols:			
Pesticides, metabolites and chlorophenols	721	1	Young g.w. special
Pesticides, metabolites	183	1/6	Old special
Chlorophenols	183	2/6	Old special
Pesticides, metabolites, chlorophenols, frequent analysis	14	4	20 in all
Other hazardous substances:			
Aromatic hydrocarbons	918	1/6	All special
Halogenated aliphatic hydrocarbons	918	1/6	All special
Ethers	104	1/6	100/67
Detergents	735	2/6	Young g.w. special
Phenols and phthalates (plasticizers)	735	2/6	Young g.w. special

Table 6.8

Monitoring programme for the Rabis Bæk groundwater monitoring site, indicating analysis type, number of screens, analysis frequency and selection principle. See parameter list, Table 6.2.

	Number of screens	Analysis frequency/yr	Selection principle
Groundwater age:			
CFC dating	112	1/6	Young groundwater
Main constituents:			
Limited programme	96	1	All screens
Limited programme, frequent analysis	16	6	2 per well
Aggressive carbon dioxide	112	0.5	Data-dependent
Methane	96	0.5	Data-dependent
Hydrogen sulphide	0	0.5	Data-dependent
Other main constituents	112	1	all screens
Field measurements	112	Every time	all screens

Table 6.9
Monitoring programme for the redox wells, indicating analysis type, number of screens, analysis frequency and selection principle. See parameter list, Table 6.2.

	Number of screens	Analysis frequency/yr	Selection principle
Main constituents:			
Limited programme, frequent analysis	60	6	15 per redox well
Field measurements	60	Every time	All screens

Table 6.10
Monitoring programme for agricultural monitoring catchments (Catchment levels 3+4), indicating analysis type, number of screens, analysis frequency and selection principle. See parameter list, Table 6.2.

	Number of screens	Analysis frequency/yr	Selection principle
Groundwater age:			
CFC dating	100	1/6	8 per LOOP
Main constituents:			
Limited programme, frequent analysis	100	6	20 per LOOP
Other main constituents	100	1	20 per LOOP
Field measurements	100	Every time	All screens
Heavy metals and inorganic trace elements:			
Limited programme	30	2/6	6 per LOOP
Limited programme, frequent analysis	10	4	2 per LOOP
Pesticides, metabolites and chlorophenols:			
Frequent analysis	40	4	8 per LOOP
Other hazardous substances:			
Aromatic hydrocarbons	40	2/6	8 per LOOP
Detergents	40	2/6	8 per LOOP
Phenols and phthalates	40	2/6	8 per LOOP

6.5.4 Groundwater monitoring in the agricultural monitoring catchments

The groundwater monitoring in the agricultural monitoring catchments describes the current state and developmental trend in the uppermost groundwater and hence is a good supplement to the other groundwater monitoring. The programme is summarized in Table 6.10. See also Chapter 5.

6.5.5 Comparison of annual frequency and sampling schedule

Table 6.11 summarizes when sample collection is to take place for the low-frequency analyses.

6.6 Data processing and quality assurance

All groundwater monitoring data are collected, quality assured and stored by the Counties, whereafter they are used in the Counties' annual reporting of the groundwater's current state and developmental trends. The data are submitted to the Geological Survey of Denmark and Greenland once yearly together with the Counties' annual reports, where they are fed into the relevant groundwater databases at the Geological Survey of Denmark and Greenland.

The well control and abstraction volume data submitted by the waterworks are also collated by the Counties for forwarding to the Geological Survey of Denmark and Greenland together with corresponding data on drinking water quality, whereafter they are fed into the relevant databases at the Geological Survey of Denmark and Greenland.

To facilitate calculation of the magnitude of groundwater recharges, including the magnitude of net precipitation, climate data encompassing corrected daily precipitation, evaporation and mean temperature are obtained (see Table 6.6).

6.7 Preconditions for implementation of the programme

Implementation of the groundwater monitoring programme presupposes:

- that all screens are tritium-dated by the end of 1998,
- that prior to initiation of sampling in 1998, all the Counties have purchased and started using an on-line instrument for collecting samples directly from wells/screens,
- that sample filtration is carried out in the field as described in the technical instruction,
- that samples that have already been screened in the field are not screened in the laboratory,
- that all completed analyses from the water supply wells are submitted together with the groundwater monitoring data,
- that the Counties calculate ion balances for all analyses and submit these to the Geological Survey of Denmark and Greenland, and
- that the water analyses from the special monitoring carried out in connection with waste depositories and contaminated sites, etc. are used to the extent that data are available.

Table 6.11
Annual number of analyses for the various groundwater monitoring parameters for each year of the monitoring programme. The analysis for inorganic trace elements or hazardous substances are to be carried out at the same time as those for the main constituents of groundwater.

Substance group	Analysis frequency/yr						Notes
	1998	1999	2000	2001	2002	2003	
Main constituents of groundwater:							
Limited programme							
Old groundwater	-	1	1	-	-	1	Table 6.2
Young groundwater	1	1	1	1	1	1	Table 6.2
Redox wells	6	6	6	6	6	6	Table 6.2
Rabis Bæk	1–6	1–6	1–6	1–6	1–6	1–6	Table 6.2
Other main constituents							
Old groundwater	-	1	1	-	-	1	Table 6.2
Young groundwater	-	1	1	-	-	1	Table 6.2
Redox wells, individual parameters	6	6	6	6	6	6	Table 6.2
Rabis Bæk, other parameters	1	1	1	1	1	1	Table 6.2
Field measurements							
Old groundwater	-	1	1	-	-	1	Table 6.2
Young groundwater	1	1	1	1	1	1	Table 6.2
Redox wells	6	6	6	6	6	6	Table 6.2
Rabis Bæk	1–6	1–6	1–6	1–6	1–6	1–6	Table 6.2
Inorganic trace elements							
Limited programme in young groundwater:							
Aluminium	1	1	1	1	1	1	Table 6.3
Arsenic	1	1	1	1	1	1	Table 6.3
Barium	1	1	1	1	1	1	Table 6.3
Lead	1	1	1	1	1	1	Table 6.3
Cadmium	1	1	1	1	1	1	Table 6.3
Copper	1	1	1	1	1	1	Table 6.3
Nickel	1	1	1	1	1	1	Table 6.3
Selenium	1	1	1	1	1	1	Table 6.3
Zinc	1	1	1	1	1	1	Table 6.3
Limited programme in old groundwater:							
Aluminium	-	1	-	-	-		Table 6.3
Arsenic	-	1	-	-	-		Table 6.3
Barium	-	1	-	-	-		Table 6.3
Lead	-	1	-	-	-		Table 6.3
Cadmium	-	1	-	-	-		Table 6.3
Copper	-	1	-	-	-		Table 6.3
Nickel	-	1	-	-	-		Table 6.3
Selenium	-	1	-	-	-		Table 6.3
Zinc	-	1	-	-	-		Table 6.3

Other inorganic trace elements:							
Antimony	-	1	-	-	-	1	Table 6.3
Boron	-	1	-	-	-	-	Table 6.3
Bromide	-	1	-	-	-	-	Table 6.3
Cyanide	-	1	-	-	-	-	Table 6.3
Iodide	-	1	-	-	-	-	Table 6.3
Chromium	-	1	-	-	-		Table 6.3
Mercury	-	1	-	-	-	-	Table 6.3
Lithium	-	1	-	-	-	-	Table 6.3
Molybdenum	-	1	-	-	-	-	Table 6.3
Strontium	-	1	-	-	-	-	Table 6.3
Silver	-	1	-	-	-	1	Table 6.3
Thallium	-	1	-	-	-	1	Table 6.3
Tin	-	1	-	-	-	1	Table 6.3
Vanadium	-	1	-	-	-	-	Table 6.3
Hazardous substances:							
Pesticides, metabolites and chlorophenols, young groundwater	1	1	1	1	1	1	Table 6.4 and 6.5
Pesticides, metabolites and chlorophenols, 20 selected screens	4	4	4	4	4	4	Table 6.4 and 6.5
Pesticides and metabolites, old groundwater	-	-	1	-	-	-	Table 6.5
Chlorophenols, old groundwater			1			1	Table 6.4
Aromatic hydrocarbons	-	-	1	-	-	1	Table 6.4
Halogenated aliphatic hydrocarbons	-	-	1	-	-	1	Table 6.4
Phenols	-	-	1	-	-	1	Table 6.4
Plasticizers, (phthalates)	-	-	1	-	-	1	Table 6.4
Anionic detergents	-	-	1	-	-	1	Table 6.4
Cationic detergents	-	-	1	-	-	1	Table 6.4
Ether, 100 selected screens	-	-	1	-	-	1	Table 6.4

6.8 Build-up of knowledge before the next revision

New substances are continually being introduced that can detrimentally affect the environment. It is therefore recommended that the occurrence and degradation of hazardous substances suspected of possibly being able to contaminate the groundwater should be documented during the coming revision period with a view to their inclusion in the monitoring programme from 2004 onwards.

In connection with the designation by the Counties of particularly valuable water abstraction areas in the 1997 Regional Plan (Ministry of Environment and Energy, 1995; Danish EPA, 1995), the developmental trend in the groundwater quality within these areas has to be monitored by means of well control by the waterworks as well as through expected strategically located new monitoring wells with a corresponding or extended analysis programme. This monitoring should in future be coupled to the present monitoring programme.

Despite the experience gained from the groundwater monitoring programme, slow progress is being made on extending the number of analysis parameters in the well control and drinking water control. In order to ensure clearly comparable analyses, a special network of existing water supply wells (high-quality wells) representing the aquifers used for the public water supply is being selected for use as monitoring wells to solve the acute need for information. It will be possible to use these for special analysis campaigns in nationwide investigations. The analysis programme for these wells, which are presently encompassed by the waterworks' well control, should therefore be extended to cover the same analysis programme as for the groundwater monitoring wells.

In order to ensure adequate amounts of groundwater suitable for the production of drinking water it is necessary not only to monitor the quality of the groundwater, but also to monitor the variation in the magnitude of the groundwater resource, among other means through data from regional and national water level measurement programmes. In this connection, an agreement has been entered into with the Danish Meteorological Institute concerning improved access to data on precipitation and evaporation.

Some Counties have already established some type of programme for measuring the groundwater level and the Geological Survey of Denmark and Greenland has a nationwide, but as yet insufficiently established programme. The groundwater level is also measured regularly in connection with the groundwater monitoring programme in the groundwater monitoring sites and agricultural monitoring catchments. These data have hitherto only been included in the groundwater monitoring to a limited degree.

In cooperation with the Danish EPA, the Geological Survey of Denmark and Greenland is preparing proposals for a new groundwater level measurement programme encompassing a regional programme with a number of stations per county and a national programme with on-line measurements from a smaller number of stations, operated by the Geological Survey of Denmark and Greenland. To this should be added possible local programmes for measuring the groundwater level.

The groundwater level stations shall monitor the effect of climatic variations and of water abstraction by major waterworks in order to improve our knowledge and be able to determine the magnitude of the groundwater resource and its development, both regionally and nationally.

The new groundwater level measurement programme will be extended in step with the establishment of the national hydrological “Denmark model” in four geographic phases, of which Funen and Zealand were completed in 1997–98 and the two Jutland parts are expected to be completed during 1998–99.

In step with the regional establishment of the groundwater level measurement programme it will be incorporated as part of the groundwater monitoring programme. Together with the other water abstraction data, this will enable estimates of the current state and developmental trend in the magnitude of the groundwater resource to be included in the annual reports of the groundwater monitoring programme.