3

The aquatic environment

The water resource in Denmark is generally sufficient, but the groundwater is threatened by nitrate and pesticides in some areas. Nutrient loading of the aquatic environment has decreased markedly over the past 10–15 years, but the environmental state of many water bodies is still poor. Hazardous substances are increasingly being detected in the aquatic environment.

Photo: NERI/Jens Skriver

3.1 Introduction

Pressure on the aquatic environment is generally related to three factors:

- Water resources and excessive water abstraction
- Physical destruction of water bodies, e.g. channelization of watercourses, drainage of river valleys and reclamation of lakes and closed fjords
- Discharge of pollutants, including nutrients and hazardous substances.

Water resources

For exploitation of the groundwater resource to be sustainable, just as much new groundwater needs to be formed as we abstract for the water supply etc. (*Figure 3.1.1*). The degree of exploitation must not be so great as to negatively affect groundwater quality and basal flow in watercourses. In practice, this probably means that between 25% and 75% of the natural groundwater recharge is exploitable. Groundwater abstraction is presently sustainable in the majority of Denmark. In the eastern part of Zealand and in some other closely populated areas, though, less new groundwater is formed than is abstracted. After periods of dry years, some watercourses can consequently dry out temporarily due to excessive abstraction.

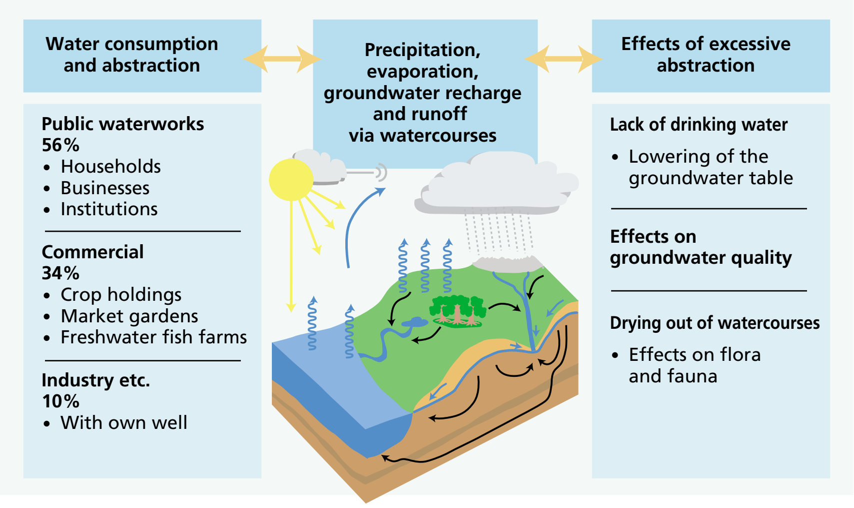
Part of Denmark's groundwater is unsuitable as a source of drinking water due to contamination with pesticides, nitrate and other substances. If the future drinking water supply is to be safeguarded, we must prevent further contamination and economize on the remaining pure groundwater.

Physical destruction of water bodies

Watercourses have been altered by societal development – especially agricultural. Fields have been extensively drained, and many watercourses have been channelized and culverted. Moreover, weed clearance has been carried out in the watercourses to ensure that the water can flow away freely. With 90% of the formerly natural watercourses, this physical intervention has

Figure 3.1.1

Conceptual diagram illustrating the relationship between water consumption and water resources. The percentages indicate the share of total water consumption (average 1996–2000).



considerably deteriorated habitat conditions for plants and animals. Many lakes and ponds have disappeared due to agricultural and urban development.

The number of natural marine biotopes, especially the coastal variety, has decreased as a result of reclamation of shallow marine areas, changes in the seabed in connection with extraction of raw materials and construction projects, and modification of the coastal areas. In addition, the environmental state of Danish marine waters is affected by fishery and the high level of marine traffic.

Nutrients

One of the main problems affecting the Danish aquatic environment is the high level of nitrogen and phosphorus loading, which both diminishes the quality of the drinking water resource and destroys habitat conditions for plants and animals. For example, drinking water with a high nitrate content is harmful to health, and many nitrate-contaminated water supply wells have consequently been closed down. Algal-green lakes, turbid and unclear water and dead benthic invertebrates in marine waters are other examples of the consequences of excessive nutrient loading.

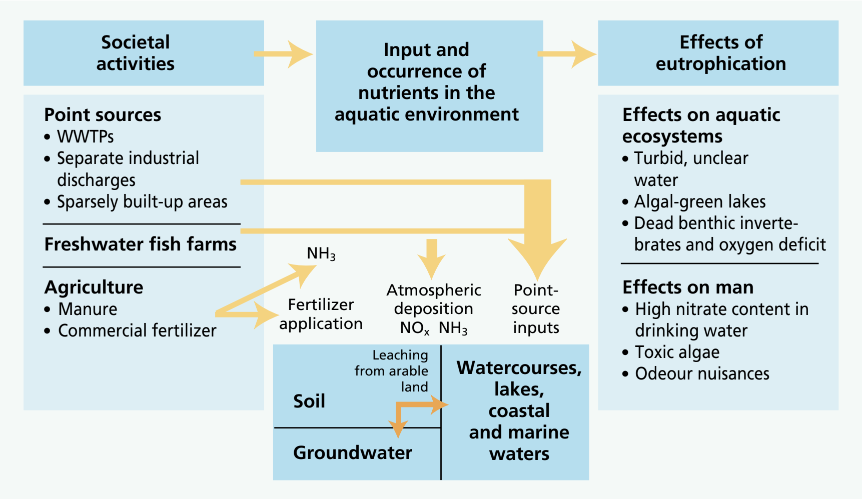


Figure 3.1.2

Conceptual diagram illustrating the relationship between human activity, input of nutrients and effects on the aquatic environment.

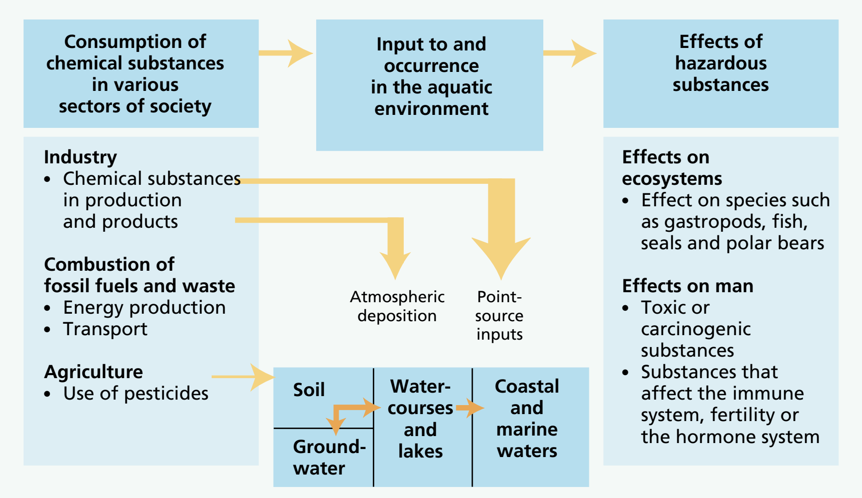


Figure 3.1.3

Conceptual diagram illustrating the relationship between consumption of hazardous substances and their occurrence and effects in the aquatic environment.

Many societal activities result in nutrients being discharged to the aquatic environment, e.g. through wastewater from households and industry and loss of nutrients from agriculture and fish farming (*Figure 3.1.2*). In some areas, atmospheric deposition of nutrients can also play a role. Agriculture is the main source of nitrogen loading and a major source of phosphorus loading, although much phosphorus also derives from point sources and sparsely built-up areas.

The effects of excessive nutrient loading are especially noticeable in the groundwater (nitrate), in lakes (phosphorus) and in the fjords, coastal waters and open marine waters. The watercourses transport much of the nutrients that are input to the lakes and the coastal waters.

Hazardous substances

Numerous hazardous substances are found in the aquatic environment that derive from our use of chemical substances (*Figure 3.1.3*). The most widespread contamination of the aquatic environment is due to pesticides and pesticide residues. Our wastewater contains many hazardous substances derived from detergents and other substances we flush into the sewers. In addition, many substances are used in industrial production and in the transport sector, e.g. the additive MTBE in unleaded petrol.

Numerous organic pollutants are found in the groundwater, including pesticides and substances leaching from contaminated sites. Pesticides also occur in watercourses. Concern is being expressed about hormone-like substances, which can change the sexual characteristics of such species as roach. In the coastal waters it has recently become apparent that hazardous substances such as the antifouling agent TBT can affect marine gastropods. Hazardous substances in the marine environment are described thematically in *Section 3.6.2*.

Photo: Roskilde County/Per Helmgaard

3.2 Inputs to the aquatic environment

The nutrients, organic matter, heavy metals and hazardous substances that are input to the aquatic environment derive from many sources. These can be subdivided into point sources and diffuse sources. The point sources encompass:

- Wastewater treatment plants, separate industrial discharges, freshwater fish farms, stormwater outfalls, sparsely built-up areas and marine fish farms.

The diffuse sources encompass:

- Cultivated land, uncultivated countryside and atmospheric deposition.

3.2.1 Wastewater and treatment plants

The wastewater that is led to the wastewater treatment plants derives from households, industry and institutions. The wastewater is typically treated in biological-chemical treatment plants, where a high percentage of the pollutants are degraded or removed.

Over the past 25 years, Denmark has made considerable investments in an effective wastewater treatment system encompassing sewers and treatment of the wastewater at treatment plants. The majority of properties in Denmark are now connected to the sewerage system, and the majority of household and industrial wastewater is led through municipal or private treatment plants before being discharged into the sea or watercourses. In 1999, the 25 largest and most advanced wastewater treatment plants treated nearly half of all wastewater.

Wastewater treatment has been considerably expanded and improved. In the 1970s, the majority of the wastewater only underwent limited treatment. Today, in contrast, the wastewater treatment plants remove the majority of the oxygen-consuming organic matter as well as phosphorus and nitrogen (*Figure 3.2.1*). Phosphorus and nitrogen removal was mainly incorporated into the wastewater treatment plants after adoption of the Action Plan on the Aquatic Environment in 1987.

Just under 60% of the wastewater led to the municipal treatment plants derives from households and service enterprises, while the remainder derives from industrial enterprises. More than 100 major industrial plants have their

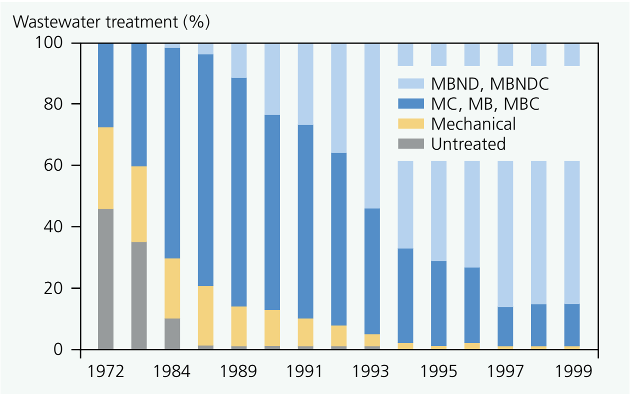
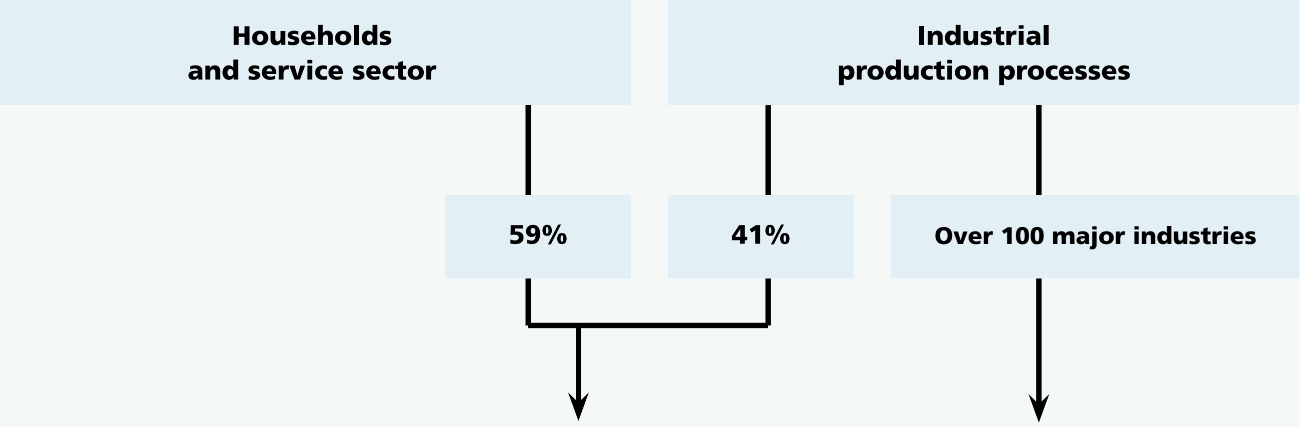


Figure 3.2.1
Trend in wastewater treatment.
Key:
M = Mechanical
C = Chemical
B = Biological
N = Nitrification
D = Denitrification
(Source: Danish Environmental Protection Agency, 2000).

Figure 3.2.2
Discharges from wastewater treatment plants.
(Source: Danish Environmental Protection
Agency, 2000).



Municipal and private WWTPs

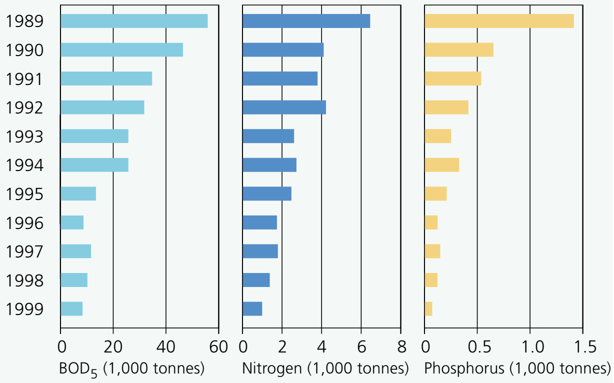
Total discharge from WWTPs

Substance (1,000 tonnes)	1989	1999	Reduction %
Organic matter (BOD_5)	36.5	3.50	90
Nitrogen	18.0	5.10	72
Phosphorus	4.5	0.58	87

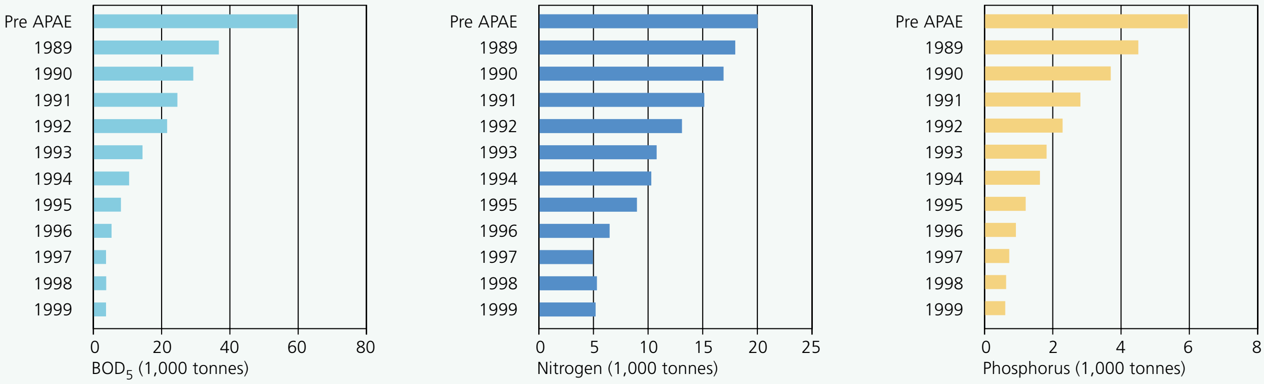
Separate industrial discharges

Discharges from separate industrial discharges

Substance (1,000 tonnes)	1989	1999	Reduction %
Organic matter (BOD_5)	56.2	8.3	85
Nitrogen	6.5	0.97	85
Phosphorus	1.4	0.07	95



Trend in discharges from municipal and private treatment plants



own wastewater outfalls and are responsible for treating the wastewater themselves. Between 1989 and 1999, the amount of organic matter discharged from municipal and private wastewater treatment plants decreased from 36,500 to 3,500 tonnes, a reduction of more than 90%. The amounts of phosphorus and nitrogen discharged have fallen correspondingly by 87% and 72%, respectively. Separate industrial discharges have also decreased markedly during the 1990s – organic matter by 85%, phosphorus by 95% and nitrogen by 85%.

Discharges of heavy metals and hazardous substances

Due to the improved treatment at the wastewater treatment plants, a greater fraction of the heavy metals and other hazardous substances is completely or partially degraded or retained in the sewage sludge (*Section 3.6.2*). The concentrations of heavy metals and hazardous substances in sewage sludge are regularly controlled (*see Section 4.4*).

3.2.2 Other point sources

Now that discharges from wastewater treatment plants have been considerably reduced, a number of formerly minor point sources have gained in relative importance. In 1999, the minor point sources such as stormwater outfalls, sparsely built-up areas and fish farms thus accounted for around 40–50% of point-source discharges of organic matter, phosphorus and nitrogen (*Table 3.2.1*).

These discharges have also decreased up through the 1990s, though. For example, phosphorus discharges from sparsely built-up areas have fallen due to increased use of phosphate-free detergents. In addition, discharges from freshwater fish farms have been halved due to the introduction of sedimentation basins and to improved feed utilization.

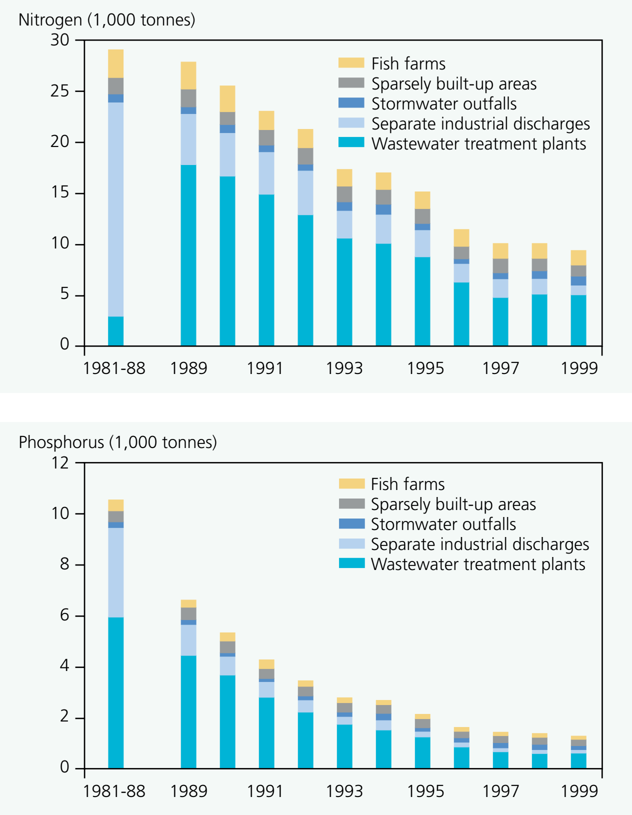
Since 1989, point-source discharges have decreased by 66% for nitrogen, 81% for phosphorus and 74% for organic matter (*Figure 3.2.3*). The reductions in nitrogen and phosphorus are

Discharge in 1999 (1,000 tonnes)	**Organic matter (BOD_5)**		**Phosphorus**		**Nitrogen**	
Wastewater treatment plants	3.5	(15%)	0.58	(47%)	5.1	(55%)
Separate industrial discharges	8.3	(36%)	0.07	(6%)	0.9	(9%)
Sparsely built-up areas	2.8	(12%)	0.25	(20%)	1.0	(10%)
Stormwater outfalls	3.8	(17%)	0.22	(18%)	1.0	(10%)
Freshwater fish farms	3.0	(13%)	0.08	(7%)	1.1	(12%)
Mariculture	1.6	(7%)	0.03	(3%)	0.3	(3%)
Total	**23.0**		**1.24**		**9.4**	

Table 3.2.1
Discharges from point sources in 1999.
The figures are in thousand tonnes.
(Source: Danish Environmental Protection Agency, 2000).

Photo: DFNA/Bent Lauge Madsen

Figure 3.2.3
Annual discharges to the aquatic environment from point sources.
(Source: Bøgestrand, 2000; Danish Environmental Protection Agency, 2000).



primarily attributable to marked reductions in discharges from wastewater treatment plants and separate industrial discharges. The reduction targets set in the Action Plan on the Aquatic Environment for these two types of discharge have been fulfilled since 1996/1997.

The atmospheric inputs of nutrients to the aquatic environment derive from both Danish and foreign emissions to the atmosphere. Around 15% of the nitrogen deposited on Danish marine waters derives from Danish sources (*see Sections 2.4 and 3.6*).

3.2.3 Nutrient inputs from agriculture

The agricultural sector in Denmark utilizes manure, commercial fertilizer, sewage sludge and certain types of industrial waste products to meet crop requirements for nitrogen and phosphorus. When the nutrients are applied in greater amounts than can be taken up by the plants, part of the surplus leaches down to the groundwater or runs off into watercourses, lakes and the sea.

The total agricultural nutrient surplus is equivalent to the amount of nutrients applied to arable land, especially in the form of commercial fertilizer and manure, minus the amount removed in the form of crops. The surplus comprises the potential loss to the aquatic and atmospheric environments. Due to changes in cultivation practice, reduced consumption of commercial fertilizer and changes in livestock production, the nitrogen surplus has fallen by 37%, and the phosphorus surplus by 32% (*see Sections 1.2 and 3.8*).

Nutrient inputs to the aquatic environment from cultivated land are difficult to measure directly. However, losses from the open countryside, i.e. cultivated and uncultivated countryside, can be calculated from measurements of downstream nutrient transport in the major watercourses and a knowledge of point-source discharges. Agriculture is the major source of nitrogen pollution, and about 4/5 of the discharges derive from cultivated land. As regards the phosphorus load, just over half derived from agri-culture in 1999, while the remainder derived from point sources.

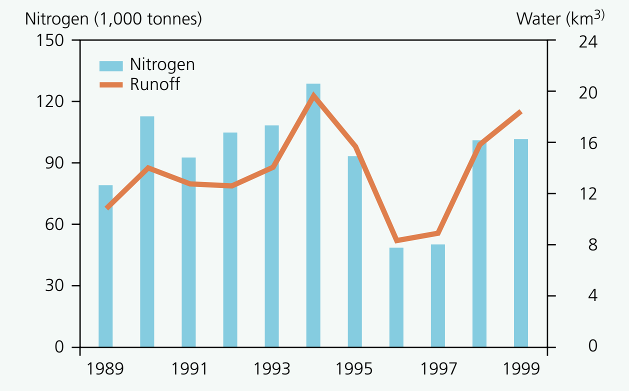


Figure 3.2.4

Trend in nitrogen loading and riverine runoff to the sea. Agriculture accounts for 4/5 of the nitrogen load. (Source: Bøgestrand, 2000).

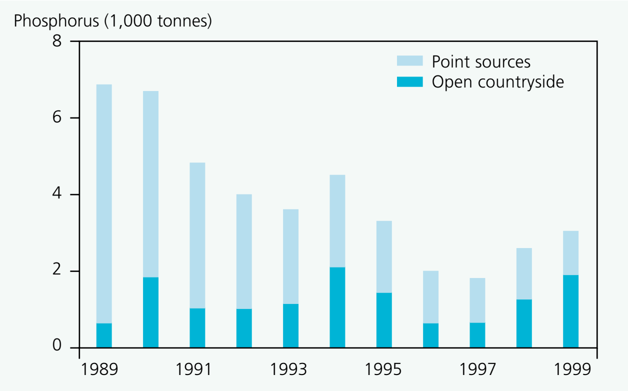


Figure 3.2.5

Trend in phosphorus loading of the sea from point sources and the open countryside. (Source: Bøgestrand, 2000).

3.3 Water resources

3.3.1 Size and variation of Denmark's freshwater resources

For the country as a whole, Denmark's sustainably exploitable water resource is greater than the total amount of water abstracted. The most recent national assessment made by the Water Council in 1992 indicated that the exploitable groundwater resource totals 1.8 billion m^3 per year, which is greater than the current water consumption of around 0.85 billion m^3 per year (*Table 3.3.1*). The Danish water supply is based almost entirely (99%) on abstracted groundwater with only a very minor part deriving from surface water.

Due to considerable regional variation, however, there is sufficient water in some areas, but insufficient in others. The net precipitation and the exploitable water resource are greatest in southwestern Jutland and least on the island part of Denmark (*Figure 3.3.1*).

As water consumption is greatest in eastern Jutland and on the island part of Denmark, the problem arises that while there is sufficient water in some parts of the country, in other areas, e.g. around Copenhagen, the water resource is overexploited.

	mm	bill. m^3
Net precipitation	300	12.00
Unexploited water resource	40	1.80
Water abstraction	20	0.85
(mean 1995–1999)		

Table 3.3.1
Water balance for Denmark.
(Source: Water Council, 1992; Geological Survey of Denmark and Greenland, 2000).

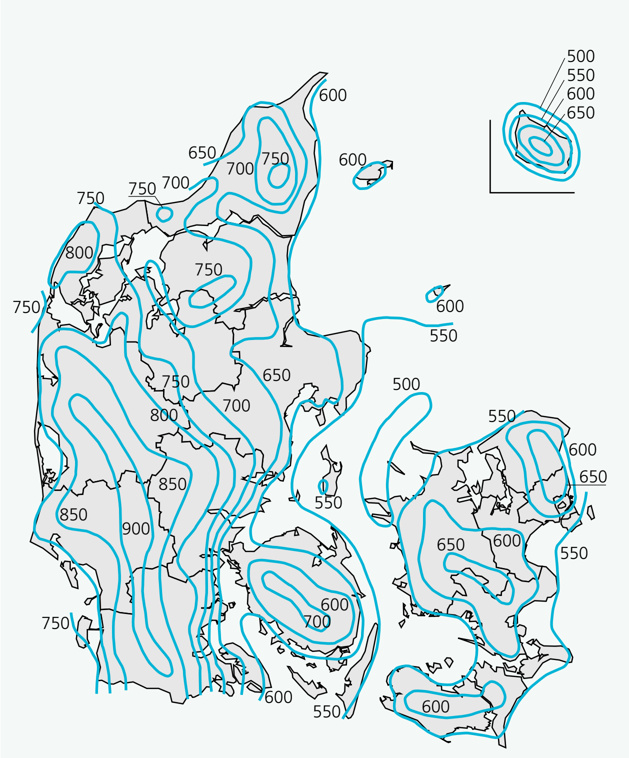


Figure 3.3.1
Annual precipitation, 1961–90.
(Source: Henriksen and Madsen, 1997; Frich et al., 1997).

For the country as a whole, 51% of the exploitable water resource is exploited. Dividing the country into four hydrologically distinct regions reveals considerable regional variation, however. Thus the Water Council estimates the degree of exploitation to be 84% on Zealand, 65% on Funen, 46% in Jutland and 33% on Bornholm (*Figure 3.3.2*). The reserves are not very large on Zealand and Funen in particular, nor in other densely populated regions such as eastern Jutland, and the situation can therefore become critical during long, dry periods.

The estimate of the size of the exploitable groundwater resource is subject to considerable uncertainty. The estimate takes into account that abstraction conditions are difficult in some areas and that the natural water quality is so poor in other areas that the water cannot easily be used. In addition, consideration for the environmental state of watercourses and wetlands places limitations on the extent to which the water resource can be utilized. Abstraction must not be so great as to detrimentally affect conditions for the flora and fauna, for example due to drying-out. Three important factors have not been taken into account in the estimate of the size of the water resource, however:

- Contamination with hazardous substances, e.g. pesticides
- The significance of long-standing climatic variation, e.g. a consecutive series of dry years
- Existing geological and hydrological data.

An estimate of the exploitable water resource adjusted for contaminated water and long-standing periods of drought will therefore yield a considerably lower figure for the sustainable water resource than the Water Council's estimate of 1.8 billion m^3 for the country as a whole. Another problem with the Water Council's estimate is that the uncertainty has not been quantified in detail. The Council's estimate is solely based on a simple assumption of the percentage of the net precipitation that is exploitable. The estimate can be rendered more reliable by incorporating the many existing hydrological and geological data.

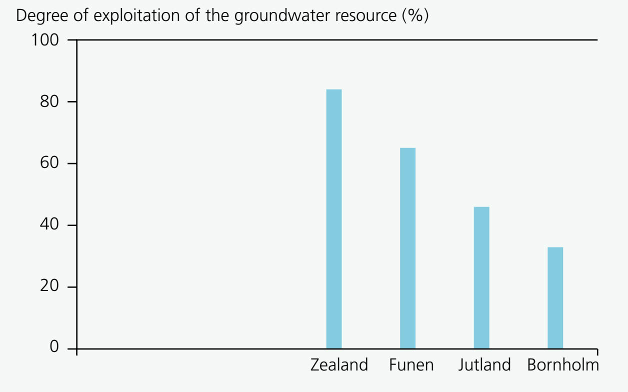


Figure 3.3.2

Degree of exploitation of the groundwater resource on Zealand and Funen, in Jutland and on Bornholm. Based on estimates by the Water Council. Copenhagen and Frederiksberg municipalities are not included in the figure for Zealand.

(Source: Water Council, 1992).

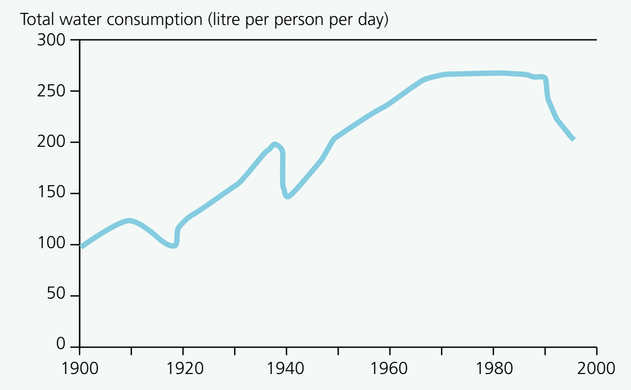


Figure 3.3.3

Trend in water consumption in Copenhagen municipality, 1900–96.

(Source: Ministry of Housing and Urban Affairs, 1999).

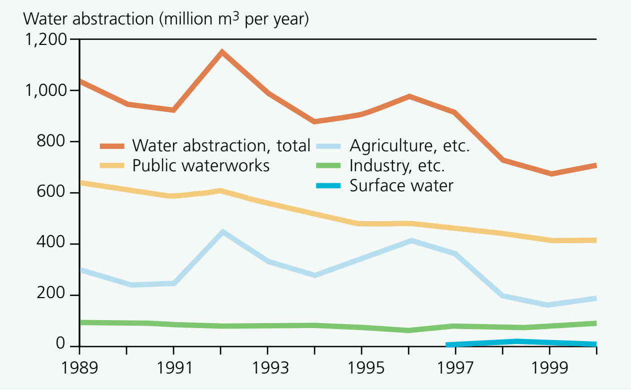


Figure 3.3.4

Abstraction of water, 1989–2000. The categories are not unambiguous as many industries obtain their water from public waterworks. Total industrial consumption thus comprises a considerably greater share. The category "Agriculture, etc." encompasses all agricultural uses, including crop irrigation etc. and water used in freshwater fish farms.

(Source: Geological Survey of Denmark and Greenland, 2001).

The Geological Survey of Greenland and Denmark is currently completing a National Water Resource model for the country as a whole that will incorporate all existing data, and which aims to quantify the size and regional distribution of the exploitable groundwater resource, including the future trend. A better estimate of the size of the exploitable groundwater resource is expected to be available at the end of 2002.

3.3.2 Abstraction and consumption of water

In 2000, the public waterworks supplied households and industry with 420 million m^3 of groundwater, and industrial enterprises and others with their own supplies used a further 98 million m^3. Market gardens, agriculture and freshwater fish farms together used 192 million m^3. The total amount of groundwater abstracted was thus 710 million m^3. In addition, 16 million m^3 of surface water was used.

Abstraction and consumption of water increased from the Second World War up to the 1970s. For example, per capita water consumption in Copenhagen municipality doubled between the Second World War and 1970 (*Figure 3.3.3*). Water consumption was relatively constant during the 1980s, but has since been decreasing through the 1990s. In 1989, the total amount of water abstracted was just over 1,000 million m^3. By 2000, the figure had fallen by 30% to 710 million m^3 (*Figure 3.3.4*). This decrease is largely attributable to the fact that water abstraction by public waterworks has fallen by 1/3 (just over 200 million m^3), but also to the relatively wet summers in recent years, which have reduced the irrigation requirements of market gardeners and farmers. In dry years such as 1996 and 1997, water abstraction for agriculture (including market gardens and fish farms) totalled about 400 million m^3. In wet years the figure was about half that.

Since 1989, household consumption of water has fallen by 30%, partly because the price of water has more than doubled since 1991 (*see Section 1.5.7*), and partly because of enhanced environmental awareness among the population, the use of water-saving plumbing such as low-flush toilets, and increased collection of rainwater. The increase in the price of water is primarily due to increases in the incorporated charges for wastewater disposal and treatment. A green tax (currently DKK 5 per m^3) has been levied on mains water since 1 January 1994, and a wastewater tax was introduced on 1 January 1998.

Water consumption by industrial enterprises with their own supplies has been relatively constant at about 90 million m^3 per year. Over the past 10–20 years, many industrial enterprises have invested in cleaner technology in order to reduce water consumption. For example, water consumption has been reduced considerably in the production of beer, livestock slaughtering and the manufacture of paper and glass wool (*see Section 1.5.5*).

3.3.3 Groundwater quality

The quality of the groundwater is threatened by various factors such as leaching of nitrate and pesticides from cultivated land and more restricted contamination from point sources such as waste chemicals deposits, landfills, oil tanks and contaminated sites.

Assessment of groundwater quality in Denmark is based on information from:

- 67 groundwater monitoring sites located throughout the country. At these sites both the young and old groundwater are monitored. The Groundwater Monitoring Programme encompasses a total of about 1,000 filters.
- About 100 filters located in the groundwater of five agricultural monitoring catchments at which the quality of the newly formed groundwater is correlated with agricultural practice in the catchment.
- In-house control by the waterworks, i.e. analyses of the water abstracted for the drinking water supply.

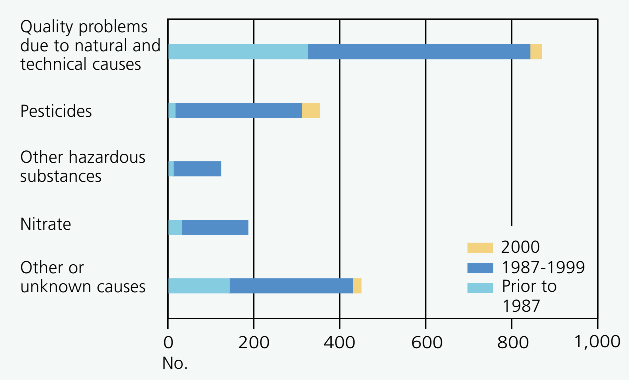
These three sources of information together provide a comprehensive qualitative impression of the chemistry and purity of the Danish groundwater.

Several water supply wells closed

The water supply in Denmark is very decentralized with 2,850 communal waterworks and approx. 90,000 individual private water supplies.

Information reported by the Counties for the period 1987–1999 shows that the waterworks have closed down quite a large number of water supply wells due to contamination resulting from human activities. Pesticides and pesticide residues account for about half of all closures. Around 20% are due to contamination with other hazardous substances, while 30% of the closures

Figure 3.3.5
Number of water supply well closures indicating the reason. (Source: Danish Environmental Protection Agency, 2001).



are due to excessive levels of nitrate in the groundwater (*Figure 3.3.5*).

The number of water supply wells closed due to contamination with pesticides or their residues has increased markedly since 1993. The increase is considered largely attributable to the greater number of samples analysed and the greater number of individual substances encompassed by the analyses.

Through the 1990s the number of wells closed due to contamination with nitrate or hazardous substances other than pesticides was relatively constant. Even though many wells have been closed because of anthropogenic contamination, an even greater number have been closed because of natural problems with the quality of the water or for technical reasons. The Water Fund, which was established at the end of 1997, is responsible for providing financial support to water supplies threatened by contamination. Between 1997 and 2000, notification of financial support has been given in 2,682 cases: 144 public waterworks, 87 private waterworks, 2,427 individual water supplies (private wells) and 24 general projects.

Nitrate in the groundwater

In many places the groundwater is contaminated with nitrate to such a degree that it becomes unsuitable as a source of drinking water. Fertilizer is used in agriculture to meet crop requirements, but more is generally applied to the fields than can be taken up by the crops, and part of the surplus leaches down to the groundwater. Drinking water contaminated with nitrate is considered to pose a health risk to infants.

About 61% of the monitoring wells and 69% of the water supply wells do not contain nitrate in concentrations exceeding the applicable detection limit (1 mg NO_3/l). Around 24% of the monitoring wells contain nitrate in concentrations exceeding the guide level for drinking water of 25 mg/l, and 18% exceed the limit value of 50

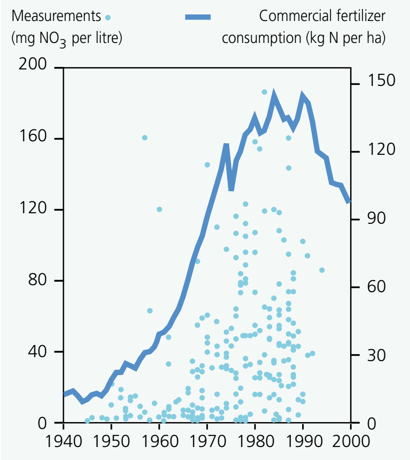


Figure 3.3.7

Relationship between the age of the groundwater, nitrate content and consumption of commercial fertilizer. Groundwater formed during the period of high nitrogen fertilizer consumption generally has a high nitrate content.

(Source: Geological Survey of Denmark and Greenland, 1999; Danish Plant Directorate, 2001).

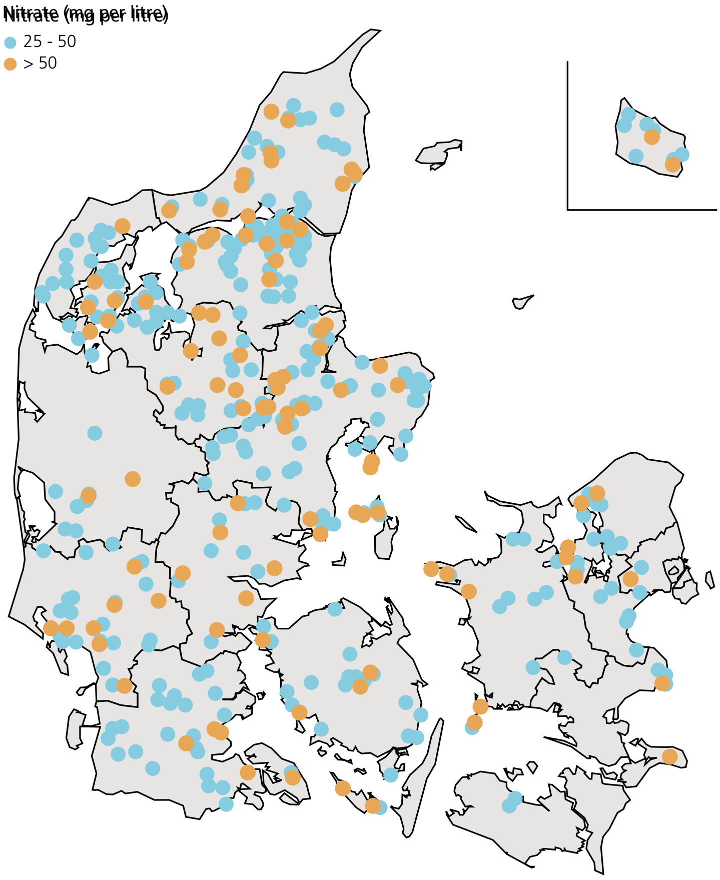


Figure 3.3.6

Nitrate concentration detected by the waterworks' in-house control during the period 1990–99. Only wells with concentrations exceeding 25 mg NO_3 per litre are included.

(Source: Geological Survey of Denmark and Greenland, 2000).

mg/l. The corresponding figures for the water supply wells are only 8.5% and 2%, respectively, among other reasons because many of the wells with a high nitrate content have been closed down, and because the water supply wells are generally slightly deeper than the monitoring wells, thus rendering them less susceptible to contamination from the ground surface.

The aquifers and waterworks most affected by nitrate contamination are located in Viborg and Aarhus counties (*Figures 3.3.6 and 3.3.8*). Nitrate contamination of the groundwater is generally smaller on the island part of Denmark.

It is particularly the groundwater formed after 1960 that is contaminated with nitrate, and a good correlation exists between the nitrate content, the age of the groundwater and agricultural consumption of commercial fertilizer (*Figure 3.3.7*).

The general assessment of the nitrate content of the groundwater is that no significant change can be detected since the adoption of the Action Plan on the Aquatic Environment in 1987 (*Figure 3.3.8*). This is as expected since by far the majority of the monitored groundwater was formed prior to the adoption of the Action Plan. On the other hand, the majority of the water currently abstracted was formed after 1950. The first signs should therefore become apparent in the next decade.

Other salts in the groundwater

Salt (sodium chloride) is found in deep groundwater and in groundwater located near the coast. The presence of salt can restrict abstraction of water for the drinking water supply. If water abstraction is excessive, intruding salt water can contaminate the groundwater. In addition, salting of roads during the winter can result in locally increased groundwater chloride and sodium concentrations.

Sulphate mainly occurs in areas where the ground contains sulphide minerals, and where lowering of the groundwater table promotes oxidation. Fluoride minerals are mainly found in limestone aquifers, where they can be released to the groundwater as fluoride.

Metals in the groundwater

Depending on the soil type, inorganic trace elements, including metals, occur in the groundwater in higher or lower concentrations. Metals occur naturally in the groundwater, but lowering of the groundwater table and oxidation of metallic minerals can raise the concentration. High concentrations of metalloids such as arsenic in the groundwater and drinking water can be extremely harmful to health.

Nickel and zinc occur in approx. 10% and 5%, respectively, of the monitoring filters in concentrations exceeding the limit value for drinking water. Both substances are thought to be released from sulphide minerals in the soil upon lowering of the groundwater table and subsequent oxidation.

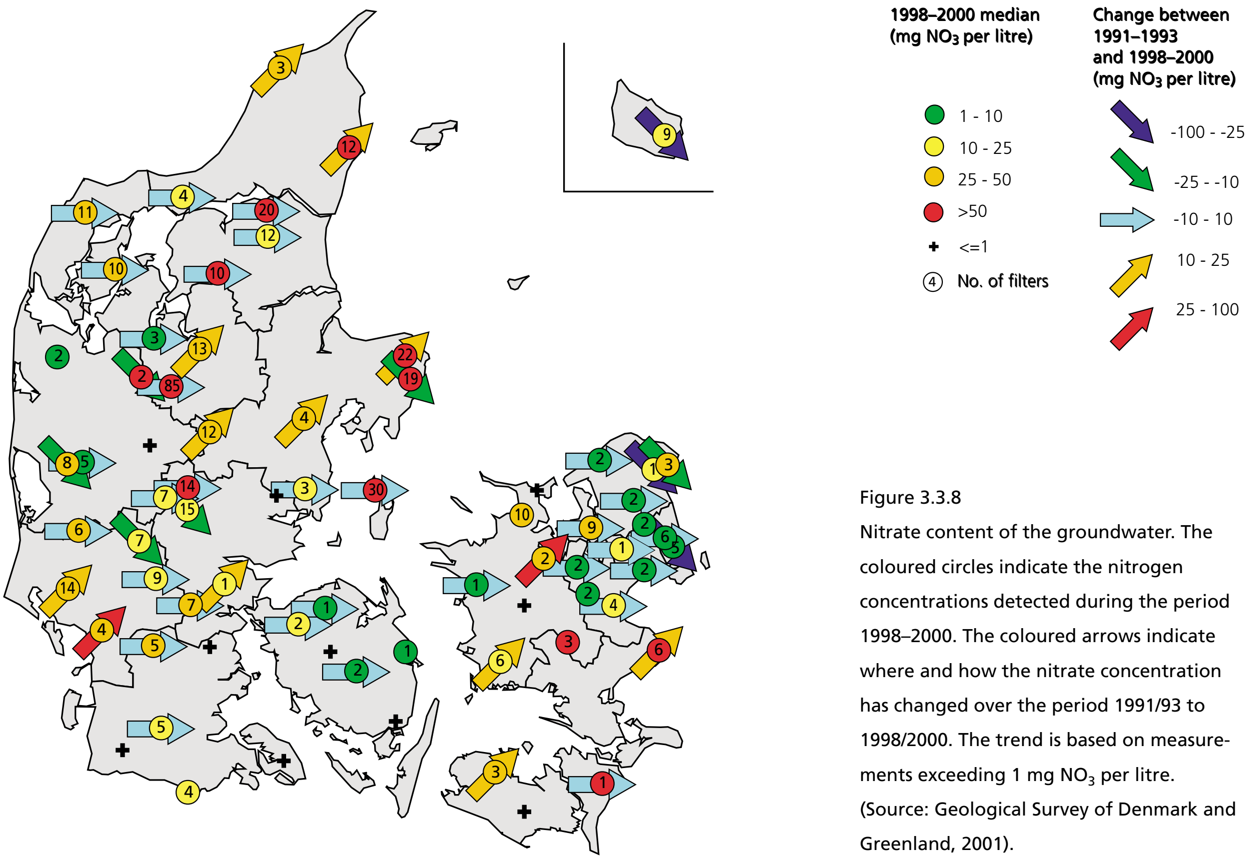


Figure 3.3.8
Nitrate content of the groundwater. The coloured circles indicate the nitrogen concentrations detected during the period 1998–2000. The coloured arrows indicate where and how the nitrate concentration has changed over the period 1991/93 to 1998/2000. The trend is based on measurements exceeding 1 mg NO_3 per litre. (Source: Geological Survey of Denmark and Greenland, 2001).

Aluminium occurs in concentrations exceeding the limit value for drinking water in 15% of the monitoring filters and in 23% of the 172 water supply wells investigated, predominantly in western Jutland, where the pH is low.

In general, though, the metals are largely retained by the sand filters at the waterworks during routine treatment of the water.

Pesticides in the groundwater

During the 1990s the programmes for analysing groundwater pesticide content were considerably expanded. In line with this, pesticides are being detected in an increasing number of groundwater monitoring and water supply wells.

The pesticides are used in agriculture, market gardens, alongside roads and railroads, as well as in private gardens. Due to the threat to the drinking water resource the Danish EPA no longer approves pesticides that leach to the groundwater if there is a danger that the limit value for drinking water will be exceeded at a depth of one metre as a yearly average.

During the period 1993–2000, the Counties and waterworks detected pesticides or pesticide residues in approximately one quarter of the wells investigated, and the limit value for drinking water of 0.1 µg/l was exceeded in 7–10% of the wells (*see Section 4.5*).

The pesticides are particularly prevalent in the youngest groundwater, of which half is contaminated by pesticides or their residues. In the majority of cases, though, the concentrations detected are below the limit value for drinking water.

Organic micropollutants in the groundwater

The groundwater monitoring programme also encompasses organic micropollutants that have been used in large amounts, have dispersed in the environment, are highly soluble in water, and which are considered to be carcinogenic or harmful to health in other ways – in particular aromatic hydrocarbons such as benzene, toluene and xylene, and chlorinated solvents such as carbon tetrachloride, trichloroethane and chloroform.

- The aromatic hydrocarbons typically derive from landfills, oil installations, petrol installations, asphalt factories, tar enterprises and gasworks. Benzene, which is one of the most frequently detected aromatic hydrocarbons, has been detected in 8% of the investigated monitoring wells.
- The chlorinated solvents mainly derive from the metals industry and the paints and dyes industry, landfills, petrol installations and dry-cleaning enterprises. Trichloroethane and chloroform have been detected in 4% and 9% of the wells, respectively. In general, the concentrations detected rarely exceed the limit value for drinking water.
- Phenols, which among other things are formed during natural degradation of organic matter, have been detected in 13% of the monitoring wells, but normally in concentrations well below the limit value for drinking water.

MTBE in the groundwater

Box 3.3.1
Organic pollutants leaching from the surface can contaminate the groundwater.

MTBE has been used instead of lead to raise the octane rating of petrol since 1985. About 50,000 tonnes of MTBE are presently used in Danish petrol each year. The MTBE content is highest – up to 10% – in 98-octane petrol. MTBE is persistent, and leakage from filling stations can therefore lead to contamination of the groundwater. Even very low concentrations of the substance cause odour and taste problems, thereby rendering the groundwater unsuitable as a source of drinking water.

During the period 1998–2000, 158 wells encompassed by the Groundwater Monitoring Programme were analysed for MTBE. The substance was only detected in one well, however. Of 238 water supply wells tested, MTBE was detected in 38 (16%). MTBE contamination of the groundwater is widespread under former filling stations, where concentrations exceeding the limit value of 0.03 mg/l for drinking water have been detected. The limit value for drinking water has solely been set to avoid poor odour and taste. Health effects only occur at higher concentrations. As MTBE is highly soluble and persistent in groundwater, it will spread from the source of contamination with the natural groundwater flow, thus entailing the risk of contaminating the water supply wells.

Because of the MTBE problem, the Danish Environmental Protection Agency entered into discussions with the Danish oil and petrol industry to find a solution. The Danish Petroleum Industry Association subsequently published a phase-out plan for MTBE in Danish petrol. According to the plan, MTBE was to be phased out of all 92- and 95-octane petrol in 2001, and sale of MTBE-containing 98-octane petrol was to be restricted to less than a tenth of the present number of filling stations, thereby considerably reducing the number of potential sources of MTBE contamination.

The phase-out plan runs until 1 January 2005. At that time more stringent EU regulations on the aromatics content of petrol could necessitate renewed addition of MTBE to 95-octane petrol. Denmark will therefore press for a more long-sighted solution to the MTBE issue at the EU level.

Photo: NERI/Annette Baattrup-Pedersen

3.4 Watercourse environmental state

3.4.1 Watercourses – particularly affected by physical changes

The Danish landscape is criss-crossed by 35,000 kilometres of natural watercourse and 25,000 kilometres of man-made ditches and canals. Watercourses have been changed considerably as a result of societal development – especially agricultural. Fields have been extensively drained, and many watercourses have been channelized or culverted. Moreover, weed clearance and in some places dredging have been carried out in the watercourses to ensure that the water can flow away freely. These measures have considerably deteriorated the habitats for plants and animals in 90% of the natural watercourses. The environmental state of the watercourses is also deteriorated by poor water quality, among other reasons due to discharges of wastewater, leaching of ochre and discharges of hazardous substances.

Wastewater from houses, farms, summer cottages and villages outside the sewerage system often severely affect small watercourses. The wastewater from a few houses can affect a small brook just as much as the treated wastewater from a whole town affects a major river.

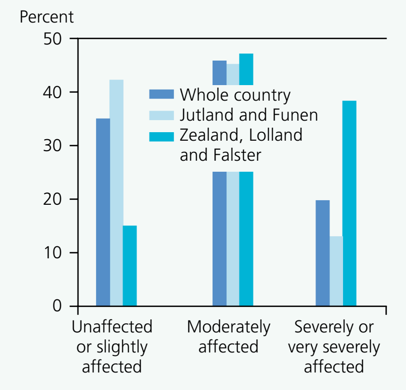


Figure 3.4.1

Biological watercourse quality in 1999 at 1,053 stations distributed throughout the country. (Source: Bøgestrand, 2000).

Macroinvertebrates indicate watercourse quality

A good indicator of the general watercourse quality is the species composition of the macroinvertebrate fauna inhabiting streams and brooks. In watercourses of poor quality there are fewer species than normal and the species present are often particularly hardy, for example species adapted to poor oxygen conditions. Watercourse quality is determined using the Danish Stream Fauna Index, which operates with seven faunal classes:

- **Fauna classes 1, 2 and 3** indicate watercourses whose fauna is severely or very severely affected
- **Fauna class 4** indicates watercourses whose fauna is moderately affected
- **Fauna classes 5, 6 and 7** indicate watercourses whose fauna is slightly affected or unaffected.

Of the national network of 1,053 watercourse stations, 46% had a moderately affected fauna (Fauna class 4) in 1999 (*Figure 3.4.1*). In these watercourses the majority of the more demanding macroinvertebrate species were either absent or present in very small numbers. At one third of the watercourse stations the macroinvertebrate fauna was unaffected or slightly affected, while at the remaining 20% of the stations it was severely or very severely affected.

The state of the larger watercourses (>5 m wide) tends to be better than that of the narrower watercourses. Only 8% of the large watercourses were severely or very severely affected as compared with 22% of the narrow watercourses.

The environmental state of the watercourses is better in Jutland and Funen than in the remainder of Denmark. In Jutland and on Funen, 42% of the stations are unaffected or slightly affected, while the figure for Zealand, Lolland and Falster is 15% (*Figure 3.4.1*). The corresponding figure for severely and very severely affected stations in the two regions are 13% and 38%, respectively. A possible explanation is that the watercourses and water discharge are smaller in the regions east of the Great Belt so that discharges from rural households and farms therefore have a greater impact.

Box 3.4.1
The river Lilleå – an example of how wastewater treatment has helped.

Wastewater treatment in the river Lilleå

The river Lilleå is a medium-size tributary of the river Gudenå at Langå. In the 1970s, the river was severely polluted by poorly treated household sewage, industrial wastewater and unlawful agricultural discharges. Several reaches of the river bed were covered with sludge and sewage fungus. The pollution from Hadsten was particularly bad because in addition to household sewage, wastewater from an abattoir was also discharged into the river. Long stretches downstream of the town were only inhabitable by the most pollution-tolerant animals.

At the beginning of the 1990s, effective wastewater treatment was established in all towns and villages in the catchment area, the unlawful agricultural discharges ceased, and the abattoir in Hadsten closed down. As a consequence, the quality of the water in the river Lilleå improved markedly, and parts of the river are now virtually unpolluted.

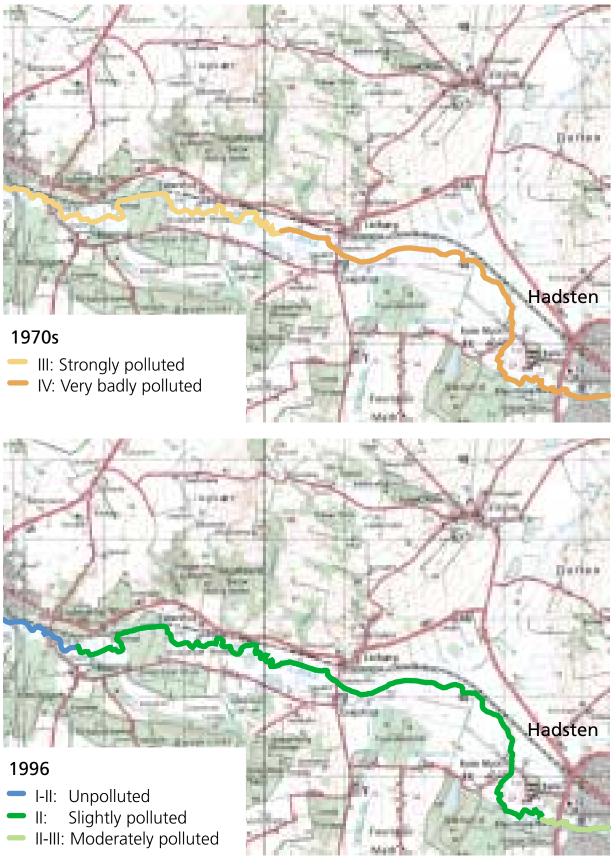


Figure 3.4.3
Environmental state of the river Lilleå near Hadsten in the 1970s and 1990s.
(Source: Aarhus County, 2000).

3.4.2 Trend in environmental state

The environmental state of Danish watercourses has generally improved over the past 10–15 years. This is especially reflected in a marked decrease in the number of severely polluted watercourse reaches. For example, the proportion of severely polluted watercourses on Funen and in Aarhus county has decreased from around 20% in the mid 1980s to the present figure of 5% for large watercourses and 12% for watercourses as a whole. At present it is mainly the small watercourses that are severely polluted. The number of watercourse reaches assessed as being affected by ochre has also fallen. These watercourses are mainly located in the counties of western Jutland.

The improved water quality seen generally, but especially in the large watercourses, is attributable to the reduced discharges of oxygen-consuming organic matter from towns, freshwater fish farms and agriculture, including the reduction in illegal agricultural discharges of slurry and leachate from manure and silage stores. In contrast to the large watercourses, many small watercourses are still affected by poorly treated wastewater from sparsely built-up areas, by drying-out in the summer and by hard-handed maintenance.

More gentle watercourse maintenance

Hard-handed weed clearance and dredging considerably affect the watercourse flora and fauna. Maintenance of many watercourses has been carried out more gently in recent years. Thus while only 26% of watercourses were not maintained at all or were maintained using only gentle maintenance practices in 1985, and 50% of watercourses were maintained in a hard-handed manner, the corresponding figures for 1996 were 52% and 7%, respectively.

Aquatic plants

Comparison of the present-day watercourse flora with that found 100 years ago reveals that many formerly common species have now disappeared (*see Section 4.3*). In a 1896 survey of 13 watercourse reaches, 16 species of pondweed were recorded. In 1996, only 7 species remained. The number of real submerged macrophytes has also decreased markedly over the past 100 years. Because of this development, the watercourse vegetation is now dominated by a fewer more widespread species that are better able to tolerate disturbances and eutrophic conditions, e.g. bur reed, starwort and Canadian pondweed.

Watercourse quality objective compliance

The county Regional Plans stipulate quality objectives for about 24,000 kilometres of watercourse. Watercourse supervision in 2000 encompassed quality assessment at 6,420 stations and revealed that the watercourse quality objectives were met at 45% of these (*Figure 3.4.2*). This hides considerable regional variation, however. Thus 70% of watercourses met their quality objectives in Ribe county, while in other counties the figure was less than 10%. During the 1990s, only about 40% of the watercourses met their quality objectives.

Figure 3.4.2

Compliance with watercourse quality objectives during the period 1990–2000.

(Source: Danish Environmental Protection Agency, 2001).

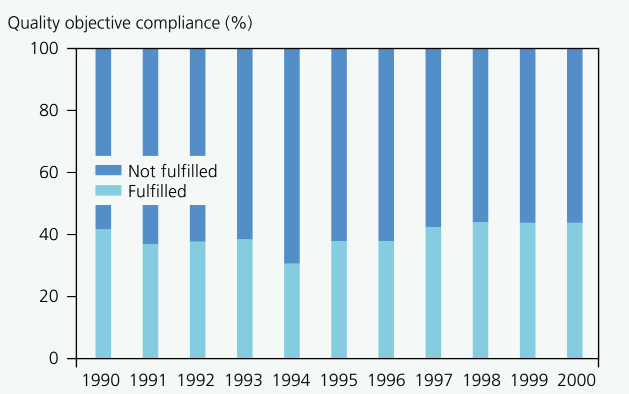



Photo: DFNA/Bent Lauge Madsen


Photo: KUBI/Dean Jacobsen

Male roach change sex

Box 3.4.2
Hazardous substances in watercourses affect the fauna. (Source: Aarhus County, 2000).

Our wastewater contains many hazardous substances, for example chemical substances from detergents or other substances we flush into the sewers. The hazardous substances in wastewater are partly degraded in the wastewater treatment plants, while the remainder is discharged into the aquatic environment.

Some hazardous substances can cause hormonal disturbances, mimicking the effects of the female hormone oestrogen. Male animals exposed to oestrogen or oestrogen-like chemicals develop female characteristics in their reproductive organs.

Odense University and Aarhus County have jointly investigated the reproductive organs of roach at three watercourse localities. In the two wastewater-polluted watercourses, the male roach had started to produce eggs in their testicles. Corresponding observations have been made in England and among marine gastropods along the Danish coasts (*see Section 3.6.2*).

It is still uncertain which substances are responsible, although suspicion focuses partly on a group of organic hazardous substances that end up in wastewater, and partly on natural or contraceptive pill oestrogen excreted by women in their urine and which is subsequently transported to wastewater treatment plants.

Photo: NERI/Martin Søndergaard

3.5 Lake environmental state

Introduction

Lakes play an important role in the Danish landscape and nature and are of great recreational value. There are around 120,000 lakes exceeding 100 m^2, the majority of which are ponds and bogs, and only just over 2,500 exceed 1 ha in size. The number of lakes has been decreasing for many years due to agricultural and urban development. For example, the number of lakes in Aarhus county decreased from 2,735 around 1900 to 835 in 1980. In recent years the trend has reversed as small lakes are now encompassed by protection regulations too, and a number of lakes that had previously been drained have now been re-established. Moreover, permission is presently granted for the establishment of several hundred new lakes and ponds each year.

The quality of the water in most of our lakes is poor. The water is often turbid, and plant and animal diversity is generally low. The submerged macrophytes have disappeared from many of the lakes, and large blooms of blue-green algae can sometimes cover the surface like a film of paint. The fish population is often large and dominated by species such as roach and bream. There are only few birds because the food resource is poor.

The Counties have set quality objectives for the major Danish lakes. Of these, 37% may only be very slightly affected by human activities, 58% may be slightly affected, and 5% may be to some extent polluted by wastewater or as a result of agricultural activities. The poor environmental state is reflected by the fact that in 2000, only approximately one third of the investigated lakes met their quality objective – roughly the same as in previous years (*Figure 3.5.1*).

The poor environmental state is attributable to the high level of nitrogen and phosphorus loading. In order to improve lake environmental state, major investments have been made over the past 20–35 years to reduce nutrient loading – not least from urban wastewater.

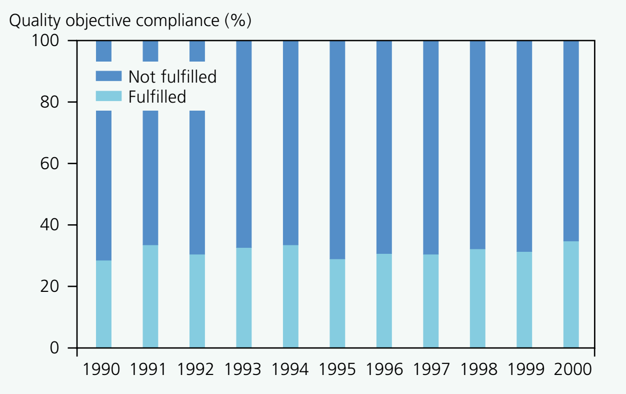


Figure 3.5.1 Compliance with lake quality objectives during the period 1990–2000. (Source: Danish Environmental Protection Agency, 2001).

Trend in lake water quality

The transparency of the water is a good indicator of lake environmental state. In clean lakes, summer Secchi depth is 2–3 metres. This is rare in Denmark, where 60% of the lakes have a Secchi depth of less than one metre, and only 25% have a Secchi depth of between one and two metres. Only 15% of the lakes have reasonably clear water. In Danish lakes that are unaffected by anthropogenic influences, e.g. lakes in woodland and natural ecosystems, the concentration of phosphorus is typically less than 0.01–0.02 mg P per litre. Nowadays the concentration in many lakes is more than ten-fold higher. As a consequence, conditions are good for phytoplankton, and the water becomes turbid during the summertime.

Based on the old literature and analyses of biological residues in various layers of the lake sediment it is known that Danish lakes were much clearer just 60–80 years ago and had a considerably more diverse flora and fauna than today. For example, the bed of shallow lakes was covered with submerged macrophytes. Today the plants have disappeared from the majority of shallow lakes.

Lake environmental state has improved somewhat since the 1970s, however. Wastewater treatment has improved, and phosphorus loading of Danish lakes has therefore decreased considerably. The phosphorus concentration in the water running into the lakes has more than halved on average during the period 1989–2000. As a consequence, the phosphorus concentration in lake water has decreased during the same period (*Figure 3.5.2*).

As a result of the decrease in lakewater phosphorus content the water in the lakes has become clearer. The Secchi depth has thus increased from 1.45 metres in 1989 to 1.6 metres in 2000 (*Figure 3.5.2*). Moreover, the biological state of the lakes has concomitantly improved.

The proportion of piscivorous fish such as pike and perch has increased, as has the capacity of the zooplankton

Box 3.5.1

Changes in lake environmental state following a reduction in nutrient loading.

Lake Søbygård

Lake Søbygård at Hammel (lake area 29 ha, mean depth 1 m) is a well-documented example of the reaction of lakes to reduced nutrient loading. Up through the 1950s and 1960s the lake received large amounts of solely mechanically treated wastewater from the town of Hammel. In the 1970s, fish death was common in the lake due to the high oxygen consumption. Biological treatment was established at the wastewater treatment plant in 1976. This was followed up in 1982 by the addition of phosphorus stripping. The latter resulted in a marked decrease in phosphorus loading of the lake (*Figure 3.5.3A*). This was subsequently followed by a reduction in nitrogen loading in 1987 following closure of the abattoir at Hammel.

Photo: NERI/Martin Søndergaard

The marked decrease in phosphorus loading only resulted in a very slow decline in the lake phosphorus concentration (*Figure 3.5.3B*) due to the release of phosphorus that had accumulated in the lake sediment. The amount of phosphorus released has been so great that the lake phosphorus balance has been negative for the past 19 years (*Figure 3.5.3A*), i.e. phosphorus output from the lake exceeds phosphorus input.

Modelling studies have demonstrated that the phosphorus pool in the lake sediment will finally be exhausted in 2016, i.e. fully 34 years after phosphorus input was reduced, and despite the fact that throughflow is rapid, the lake's hydraulic retention time only being one month. Conversely, the decrease in lakewater nitrogen concentration seems to follow the decrease in nitrogen loading without any delay.

Changes have started to occur in the biological state of the lake. The amount of algae (expressed in terms of chlorophyll *a* concentration) has fallen, and the water has become clearer (*Figure 3.5.3C*). The fish community has also changed markedly. While the total catch has only decreased slightly, the percentage of piscivorous fish has increased markedly from almost nothing to 34% of the total catch (*Figure 3.5.3D*). The percentage of piscivorous fish is now so high that they are able to regulate the prey fish population, which mainly consists of roach. The dominant piscivorous species is the perch, but pike and zander are also well represented. Such an increase in the percentage of piscivorous fish in the fish community has also been observed in a number of other Danish lakes following reduction of phosphorus loading.

to graze down the phytoplankton. In addition, the submerged macrophytes are gaining ground.

Phosphorus input to some of the lakes is still too high. In other lakes, part of the phosphorus that has been input to them over the years has accumulated in the sediment from where it is being released, detrimentally affecting their environmental state. In some cases it can be necessary to take further measures to reduce nutrient loading, especially from sparsely built-up areas and cultivated land.

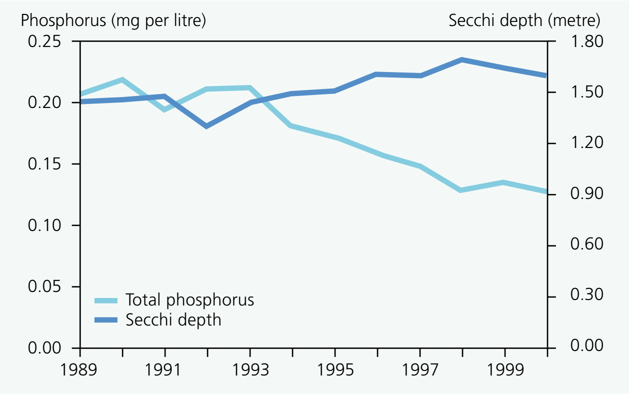


Figure 3.5.2

Trend in average phosphorus concentration and Secchi depth in the lakes encompassed by the monitoring programme during the period 1989–2000.

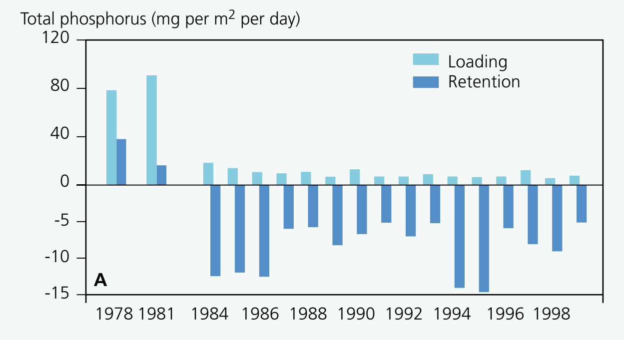
(Source: Jensen et al., 2001).

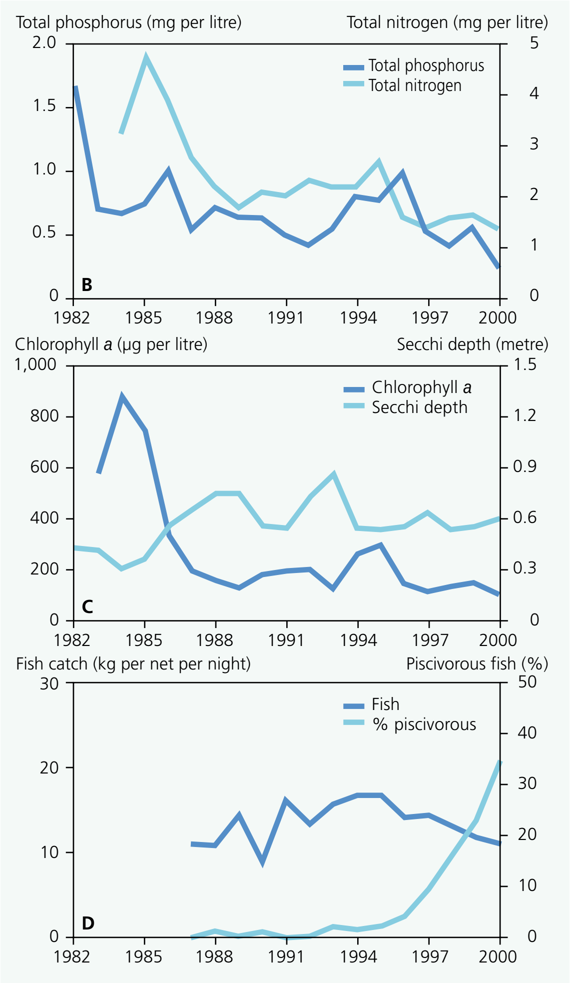
With the marked increase in the proportion of piscivorous fish in recent years it is hoped that conditions will soon improve for the larger zooplankton because of increased predation on the roach, which eat the zooplankton. When the zooplankton population increases, so will grazing pressure on the algae, thereby reducing the turbidity of the water. Phosphorus loading needs to be reduced further, though, if the lake is to shift to a stable clearwater state with numerous submerged macrophytes and a dense population of aquatic birds, i.e. corresponding to the state of the lake during the first half of the 20th century as revealed by studies of various biological remains in the lake sediment.

Figure 3.5.3

Trend in phosphorus input, phosphorus and nitrogen concentrations, chlorophyll *a* concentration and Secchi depth, fish catch and percentage of piscivorous fish in Lake Søbygaard.

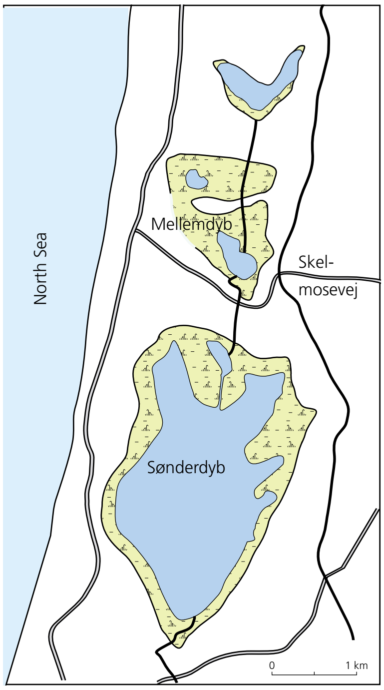
(Source: Søndergaard *et al*., 2001).





West Stadil Fjord

Box 3.5.2
Nature restoration
of West Stadil Fjord



West Stadil Fjord is a large, open and flat wetland that serves as an important breeding and staging ground for ducks, geese and wading birds. The nature restoration project has beneficially affected 13–14 of the 19 species in the area that are included on the Danish Red and Yellow Lists – without this having negatively affected the other populations.

A number of nature restoration projects have been carried out in Denmark over the past 10–15 years. These have encompassed many different types of project from ponds of a few hundred square metres to lakes and wetlands of several hundred hectares. One of the largest projects was carried out in 1998 at West Stadil Fjord – a 2,200-hectare natural ecosystem north of Ringkøbing.

Until 1865, West Stadil Fjord was a fjord branch openly connected to Stadil Fjord and Ringkøbing Fjord. Drainage of the area was then initiated, and by 1954 only three deeps remained: Sønderdyb (approx. 330 ha) and two smaller deeps, Mellemdyb and Nordre Dyb (combined area of less than 100 ha).

In autumn 1998, part of the drained land was returned to nature by raising the water level in the two small deeps by one metre. The aim was partly to create larger contiguous wetlands and partly to enhance nutrient retention in the new wetlands and thereby reduce phosphorus input to Sønderdyb deep, which receives its water from these two wetlands.

The project was followed up by a monitoring programme encompassing water chemistry, birdlife and the vegetation. The monitoring programme revealed that the project has hitherto been successful. The phosphorus content of the water in Sønderdyb deep has fallen from an average of 340 µg/l in 1998 to 90 µg/l in 2000. The water is still very turbid, among other reasons because it is very shallow, and the wind therefore resuspends the sediment into the water. From 1998 to 2000 the average Secchi depth nevertheless increased from 0.2 to 0.6 metre, resulting in marked improvement in the distribution of submerged macrophytes. Average coverage has increased from 8 to 31%, and the plant-filled water volume has increased from 3 to 16%.

The project has hitherto been a success as regards the bird population too, with nearly all species having increased in number. This also applies to the large flock of staging geese, some of whose foraging grounds were flooded by the project. They soon found other foraging grounds, and there are now just as many geese as before the water level was raised. The fact that the water is so shallow entails the danger that the newly established wetlands could become overgrown if left to themselves. If the large bird population is to be maintained, it can therefore become necessary to implement management measures such as cattle grazing, grass cutting or irrigation of areas that would otherwise dry out too quickly during the bird breeding season.

Photo: Erik Thomsen

Photo: NERI/Peter Bondo Christensen

3.6 Coastal waters

3.6.1 Trend in pressures and state

The inner Danish marine waters can generally be characterized as shallow and stratified. Of Denmark's 105,000 km^2 of marine waters, just under 33,000 km^2 are less than 20 metres deep. Of the latter, more than 75% are located east of the line between Skagen and Norway, where they comprise 56% of the marine area.

During periods the water masses can be stratified, and the oxygen concentration in the bottom water can be lower than at the surface. In the nutrient-rich, shallow stratified coastal waters, the bountiful phytoplankton production and the often luxuriant plant growth on the seabed provide ideal conditions for a relatively high number of faunal species.

The state of the marine nature has changed in a number of respects since the beginning of the previous century, among other reasons due to land reclamation, intensive fishery and discharges of nutrients and hazardous substances. The majority of the populations of mammals (seals and porpoise) and birds are stable, but very sensitive to pressures. Many of the commercial fish stocks are extremely overexploited (*see Section 1.5.2*).

The majority of the Danish fjords, coastal waters and inner marine waters do not meet the environmental quality objectives set for them by the Counties. The main hindrances to compliance with the environmental quality objectives are the occurrence of oxygen deficit, the large amounts of pollution-tolerant algae and phytoplankton blooms.

The marine waters around Denmark are very sensitive to interannual climatic variation. The generally high nutrient levels entail the potential risk of massive algal blooms and that oxygen deficit can occur when the right climatic conditions are present. Observations made in recent years indicate that the marine environment deteriorates in years with high precipitation and hence high nutrient runoff, as well as in years with prolonged windless periods in the summer, while marked improvement is seen in dry years such as 1996 and 1997.

Some signs of positive trends are seen in the period following adoption of the Action Plan on the Aquatic Environment in 1987. The most obvious is the falling phosphate concentrations, but the amount of phytoplankton also shows signs of decreasing. At the present time the quality objectives for coastal waters are not met, and the state of the open marine waters also needs to be improved. In order to further improve the marine environment it is necessary to reduce nitrogen loading, as stipulated in the first and second Action Plan on the Aquatic Environment (*see Section 3.8*).

Photo: NERI/Peter Bondo Christensen

Marine nature and biodiversity are affected by a large number of human activities. The number of natural marine biotopes, especially the coastal variety, has decreased as a result of reclamation of shallow marine areas, changes in the seabed in connection with extraction of raw materials and construction projects, and modification of the coastal areas. In addition, the environmental state of Danish marine waters is affected by fishery and the high level of marine traffic. Inputs of nutrients and heavy metals also considerably affect the marine environment.

Ship traffic

The Danish marine waters are among the busiest in the world. Shipping affects marine ecosystems to a greater or lesser extent physically through noise, disturbance, mixing of water masses, chemically through the effects of hull paints and oil spills, and biologically through the introduction of alien species.

When rapid catamaran ferries sail close to important staging and foraging grounds for aquatic birds they can pose a threat to these species, for example during periods when the birds moult and do not have the possibility to fly away from the shipping lane, and during the wintertime, when the foraging period is so short that all daylight hours are of vital importance to their survival. Approximately 10 rapid catamaran ferries have been authorized to sail in Danish marine waters, of which some only sail during the summertime.

Waste pollution along the main shipping lanes poses an increasing problem, not least because a large proportion of it consists of plastic and synthetic substances that are persistent in the environment. In certain areas, 90% of the waste along the beaches consists of plastic. The waste is transported by the sea currents and concentrates locally such that aquatic birds in particular can be harmed, for example by becoming entangled in netting and ropes or by swallowing waste.

Land reclamation, structures and construction activities

The extent of shallow coastal waters has been reduced over the years, partly through reclamation for agricultural purposes and partly by being filled up in connection with the construction of infrastructure and industrial plants. Over the past approximately 250 years, 45,000 ha have been reclaimed (an area corresponding to Falster). About 20% of the shallow waters with a depth of less than 2 metres have thus been reclaimed. As a result of land reclamation projects, 140 small islands and islets have become connected to the mainland, and the coastline has been reduced by 14% from 8,000 to 7,000 kilometres (*Figure 3.6.1*). As a consequence, the extent of natural marine biotopes in productive fjords and coves with a diverse flora and fauna has been considerably reduced. The majority of the reclaimed land was not placed under intensive agriculture until after the Second World War. Intensive agriculture is still the dominant land use in the reclaimed areas, although land is increasingly being converted to extensive use as a result of the agri-environmental measures scheme and nature restoration. This extensification process can be expected to continue as part of efforts to fulfil the targets stipulated in Action plan on the Aquatic Environment II. At some reclaimed areas, in particular

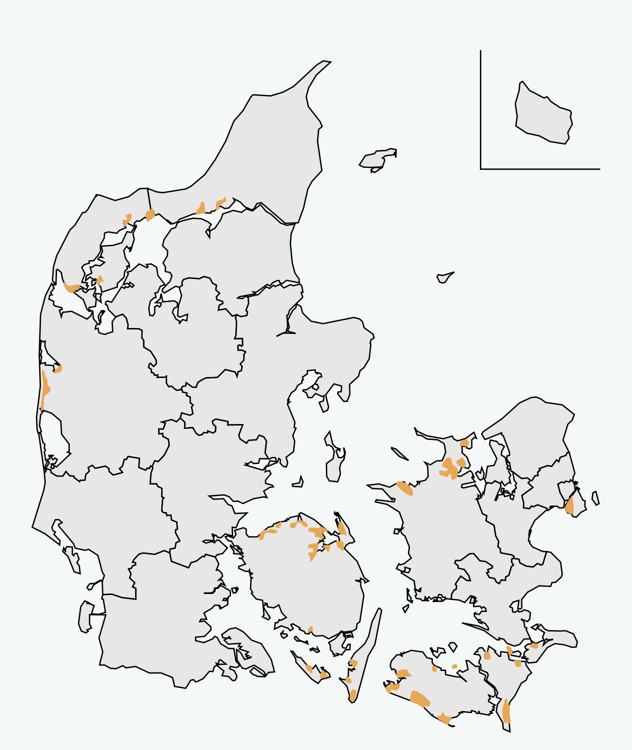


Figure 3.6.1
Land reclamation work carried out up to 1953.
(Source: Redrawn from "Denmark's Nature", 1980).

those where hope of complete drainage has been abandoned, important biological and recreational areas have been created, e.g. the Vejlerne, Saltbæk Vig and Vestamager (*Figure 3.6.1*).

Raw materials extraction at sea

In the past, raw materials could be freely extracted at sea except in coastal areas – where extraction was prohibited – and in other designated areas (*see Section 1.5.3*). Since implementation of the Raw Materials Act in 1997, however, the permission of the Danish Forest and Nature Agency is required, and extraction has to be carried out in delimited areas following an environmental assessment.

Offshore extraction of raw materials is carried out at approx. 150 designated extraction zones. The total area designated for raw materials extraction is approx. 1,000 km^2, but less than 1% of this is affected by actual extraction. Some areas are of regional significance and have been heavily exploited for many years.

Extraction is normally undertaken at depths ranging from 6 to 20–25 metres. The dredging process removes the flora and fauna where suction is carried out, and changes the bottom conditions. Dredging can also lead to resuspension of fine particles in the water column, which reduce light penetration, and which subsequently settle on the seabed again inside and outside the extraction area.

The plant community and spawning grounds for certain species of fish, e.g. herring and sand eel, can be destroyed by changes in seabed conditions.

The biological significance of Danish stone reefs is generally considered to be high because they contain a very varied plant and animal community, and because they are of significance for life in the surrounding free water masses and serve as a foraging area for certain seabirds. Extraction of boulders directly affects habitat conditions for plants and animals that live on hard seabed by removing the substrate to which they adhere. No data are available for the busy construction periods in the 1960s, but a conservative estimate is that boulder extraction in Danish marine waters has eliminated 15 km^2 of hard seabed.

Most extraction of boulders in the 1960s was carried out at water depths of less than 10 metres, with cavity-forming stone reefs (stone reefs in which the boulders are stabled on top of each other) being the preferred source. As a consequence, this type of habitat is very rare now. Extraction of boulders is now very restrictively regulated (*see Section 1.5.3*).

Wind turbines

According to the energy action plan "Energy 21", 4,000 MW of offshore wind power is to be established before 2030. The five planned demonstration wind farms that are to be established in Danish marine waters in the years to come will together encompass 450 wind turbines and cover an area of about 150 km^2 (*see Section 1.3.1*).

Offshore wind turbines can affect birds and mammals due to disturbances during the construction and operation phases. In addition, they entail a collision risk and can lead to changes in sedimentation, vegetation, benthic fauna and the fish population.

Photos: NERI/Karsten Dahl

The fixed links

Construction of the fixed links across the Great Belt and the Øresund was accompanied by extensive studies of their impact on the environment. The studies of the Great Belt Fixed Link showed that plants and animals had generally returned to the areas affected by its construction. The common mussel population was markedly affected during the construction phase. The common mussel and eelgrass have now regained their former abundance, although their distribution differs from earlier.

The studies at the Øresund Bridge show that environmental conditions have only been slightly affected. None of the changes recorded exceeds the criteria set for the environmental impact of the construction work. Moreover, results obtained with two independent three-dimensional models show that according to the criteria used, water flow in the Øresund remains unchanged, as do oxygen and salt transport to the Baltic Sea (the so-called zero-solution).

Box 3.6.1

Impact of fixed links on nature and the environment.

Harbours, bridges, dams and coastal defences

Over the past 10–15 years, considerable attention in Denmark has focused on the environmental impact of the construction of the Great Belt Fixed Link and the Øresund Bridge (*Box 3.6.1*). In accordance with the Planning Act, an environmental impact assessment must be carried out for major construction projects that are likely to considerably affect the environment.

Free coastal dynamics are hindered along much of the coast due to various forms of coastal defences. The Coast Directorate estimates that of the approx. 5,883 km of coast adjoining Danish inner

Box 3.6.2

Oil pollution.

Oil pollution

Oil pollution derives both from actual accidents, e.g. groundings, and from illegal discharges of waste oil from tankers. The discharge of waste oil into the sea is prohibited throughout Danish marine waters, and the harbours are required to provide oil reception facilities.

It is not possible to give exact figures for the amount of oil illegally discharged into Danish marine waters each year. However, it is possible to illustrate the extent of the problem using examples of the number and distribution of oil pollution incidents over the years. State and municipal expenditure on remediation of oil-polluted beaches varies considerably from year to year. In 1995 and 1999, a total of DKK 4–5 million were spent on the task. In 1996 and 1997, the annual expenditure was around DKK 1.5 million, while that in 1998 and 2000 was about DKK 0.8–0.9 million. The number of reports on oil pollution incidents in Danish marine waters has remained rather constant over the past 5–10 years at around 400 per year despite a general increase in ship traffic. The number of reports cannot be used directly as an indicator of whether there is a serious oil pollution problem in Denmark, though. As a rule, more than half of all the observations concern either light oil or diesel, which evaporate, or mud, algae or marine current boundaries, which thus prove to be false alarms.

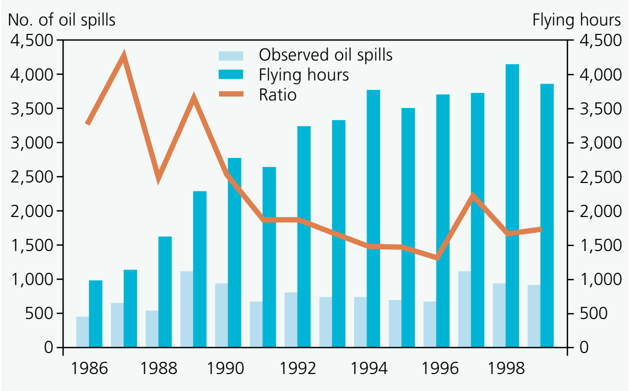
According to the Helsinki Commission, 435 oil spills were recorded in the Baltic Sea in 1999. By far the majority of these were located along the busy shipping lane that passes through the Øresund and the Danish belts, and south of Gotland on the way to the Gulf of Finland and the Gulf of Riga (*Figure 3.6.2*). In the North Sea, around 500–1,000 oil spills were observed annually during the 1990s. As aerial monitoring has quadrupled during the same period, the results can be interpreted as indicating a decrease in the number of oil pollution incidents (*Figure 3.6.3*). In 1999, 840 oil spills were observed in the North Sea (*Figure 3.6.3*).

Denmark experienced major oil pollution incidents in both 1998 and 2001. In January-March 1998, the Wadden Sea and the western coast of Jutland were affected. In March-April 2001, Møn, Bogø and northern Falster were affected by oil pollution

Figure 3.6.3

Trend in number of observed oil spills in the North Sea for the period 1986–1999.

(Source: Bonn Agreement, 2000).



marine waters, dykes protect more than 934 km, and a further approx. 700 km are protected by other coastal defences. Thus 28% of the inner coastline is protected. In addition, there are 13,000 groynes, breakwaters, etc. and 6,000 outer jetties, etc. These modifications of the coastal areas often result in changes in valuable habitats and disturbances of ecological functions.

Other pressures

There are presently just over 40 oil and gas production platforms in the Danish sector of the North Sea. In addition there are various associated facilities, internal pipelines and three pipelines transporting the oil and gas to shore. Both the exploration and production phases affect the water, plants and animals in the sea in the vicinity of the platforms.

The effects are mainly attributable to the discharge to the sea of production water contaminated with oil residues and production chemicals (*see Section 1.3.1*). Around 1 million tonnes of chemicals are used annually in offshore activities in the North Sea, of which about 50,000 tonnes are used in the Danish part. The majority are harmless, but a minor part containing oil and heavy metals are harmful to the environment.

The main impacts of fishery on marine ecosystems are the harvesting of target species, damage to the seabed caused by the use of beam trawls, etc. and the by-catch and discard of non-target species. Many fish stocks in the North Sea, the Kattegat and the Baltic Sea are overexploited (*see Section 1.5.2*), and if this trend continues, some of them may collapse.


Photo: CDanmark

The environmental effects of mariculture are mainly detectable in the immediate vicinity of the fish farms and the nearby waters. Nutrient and especially organic matter losses from the fish farms often cause changes in the surrounding seabed, and in the worst cases can eradicate all life in the affected area (*see Section 1.5.2*).

from a ship collision in the Kadetrenden. When oil pollutes our coasts and beaches, it impacts on their recreative value and can thereby affect the tourist industry in the region. In nature, oil can also cause considerable damage to ecosystems, animals and plants. The best known effect is on seabirds, whose plumage forms an effective water-repellent and insulating layer. When a bird comes into contact with oil, this protective layer is destroyed and the feathers stick together.

Shallow-water areas, which are very productive during the summer and home to fish fry, are especially vulnerable to oil pollution. In winter, the Danish marine waters house large populations of diving ducks, etc. at a time when they are vulnerable to oil pollution. Bird death due to oil pollution is thus almost solely observed during the winter period from October to April. The pollution primarily affects eider ducks, common scoters, velvet ducks and long-tailed ducks. Relative to the 1970s, when up to 100,000 birds may have perished, the number of bird deaths as a result of oil pollution has fallen considerably. Although oil pollution no longer seems to pose a threat to the populations, it still poses an animal welfare problem. Thus up to 20,000 common scoters perished in connection with an oil pollution incident in January-March 1998, and about 3,500 birds perished in April 2001 in connection with the oil spill affecting Møn, Bogø and northern Falster. An investigation of the number of oil-coated birds during the period 1984 to 1995 shows a decrease in the number in the Baltic Sea and the Kattegat. A corresponding fall has not been detected in the Skagerrak and the North Sea.

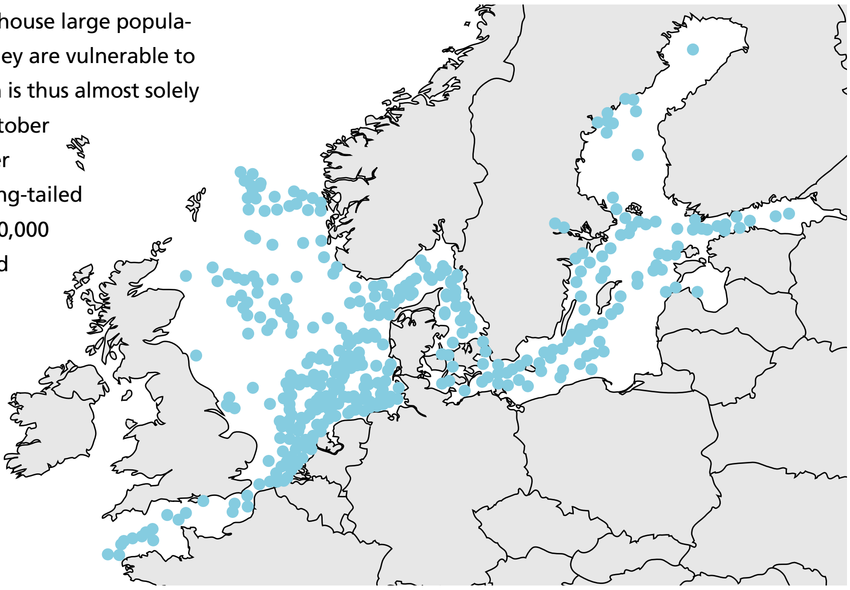


Figure 3.6.2

Observed oil spills in the Baltic Sea and the North Sea in 1999.

(Source: German Oceanographic Data Centre, 2000; Bonn Agreement, 2000).

Eutrophication

One of the main environmental problems affecting the sea is eutrophication caused by excessive nutrient loading (nitrogen and phosphorus). The main sources of nutrient input to the sea are riverine runoff and atmospheric deposition on the sea surface, although some is accounted for by direct discharges of wastewater and input from adjoining marine waters.

The effect of eutrophication is increased phytoplankton production during the warm summer months. The phytoplankton decompose in the late summer leading to considerable consumption of oxygen. Under unfavourable weather conditions characterized by high temperatures and little wind, decomposition of the phytoplankton will lower the oxygen concentration to such low levels that the fauna will not survive. Such a situation arose in Mariager Fjord in August 1997. The increased nutrient levels shift the competitive balance in favour of rapidly growing filamentous algae, reduce the transparency of the water and deteriorate conditions for submerged macrophytes. Studies made over the past 10–15 years have demonstrated effects such as oxygen deficit, phytoplankton blooms, reductions in the eelgrass population and changes in the biological structure of the affected communities.

Input of nutrients

Input of phosphorus and nitrogen to the sea from the Danish land mass has increased due to increased discharge of wastewater and increased agricultural production, especially since the 1950s. The Danish contribution to the nutrient concentration in the inner Danish marine waters is thus considerable and measurable, especially in areas where riverine runoff is high. The concentration of nitrogen in the fjords and coastal waters is generally high and often considerably increased relative to the open marine waters. The concentrations of nutrients in the inner Danish marine waters are far higher than the natural background

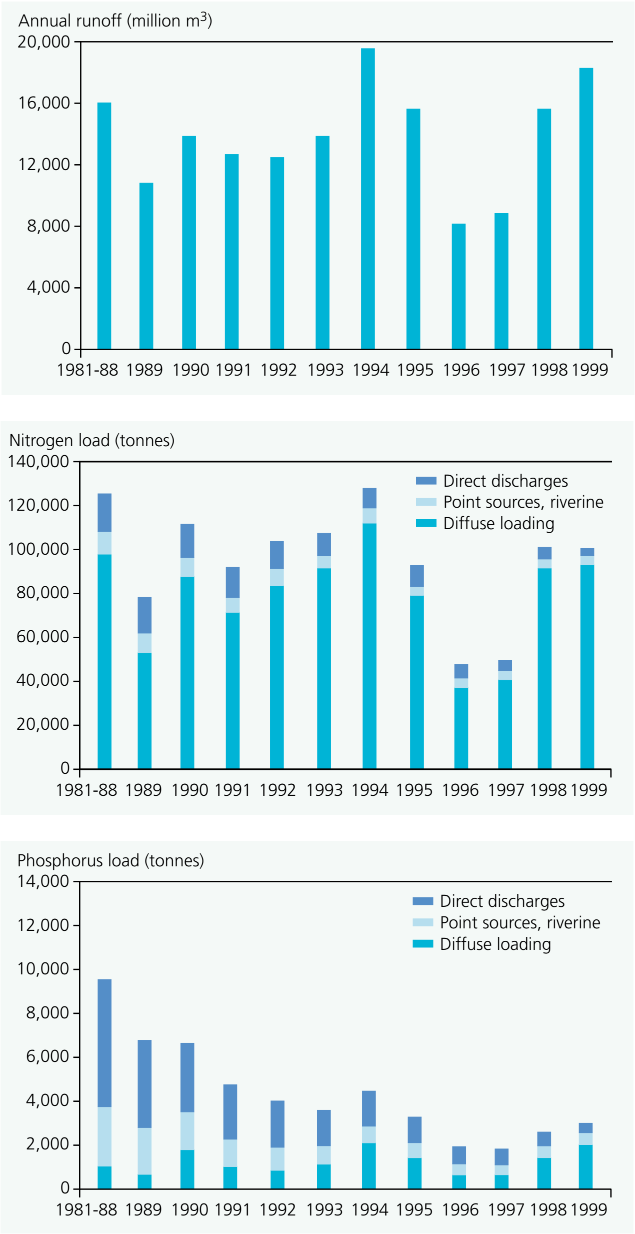


Figure 3.6.4
Freshwater runoff and input of nitrogen and phosphorus to the marine environment for the period 1989–99 and an estimated average for the period 1981–88.
(Source: Bøgestrand, 2000).

levels, despite the large water exchange between the Baltic Sea and the North Sea.

Nitrogen input to marine waters closely correlates with the amount of precipitation and riverine runoff (*Figure 3.6.4*) and averaged 100,000 tonnes during the 1990s.

In addition to riverine input of nitrogen, the Danish marine waters also receive approximately the same amount of nitrogen from the atmosphere by deposition (*see Section 2.4*). In the open marine waters, atmospheric deposition accounts for a considerable proportion of the total input. In the Kattegat, atmospheric deposition is thus equivalent to one third of the riverine input, while in coastal waters it comprises only a small part.

Phosphorus inputs have decreased markedly over the past 10 years, largely due to improved wastewater treatment. As with nitrogen, phosphorus input from the open countryside varies with riverine runoff.

Nutrient levels in the water column

The nitrogen concentration in the fjords and coastal waters remained roughly constant during the 1990s and was slightly lower in years with little input from the land (e.g. 1996 and 1997) and particularly high in years with high input from the land (e.g. 1994) (*Figure 3.6.5*). The variation was much less in the open parts of the inner marine waters.

The phosphorus concentration in the fjords and coastal waters decreased during the 1990s and is presently only about half that at the end of the 1980s (*Figure 3.6.6*). Decreasing phosphorus concentrations have also been detected at the open marine water stations in the North Sea, Skagerrak, Kattegat, Belt Sea, Øresund and Baltic Sea, particularly in the winter months.

Photo: Lars Angartyr

Figure 3.6.5

Trend in annual mean concentration of total nitrogen at stations (estuarine fjords/coastal and open parts of the inner marine waters) encompassed by the Nationwide Monitoring Programme for the period 1989–2000.

(Source: Henriksen et al., 2001).

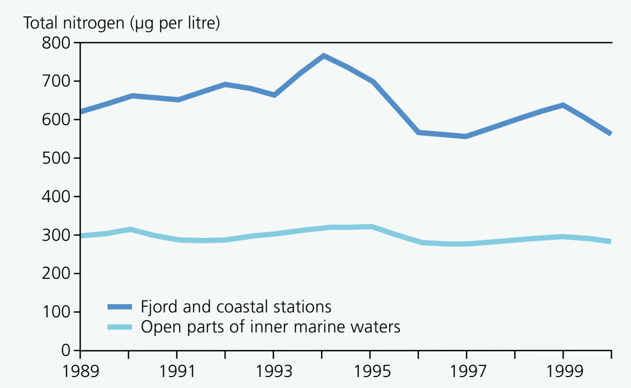
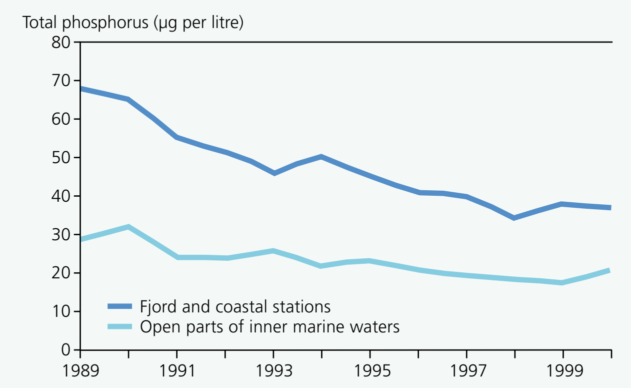


Figure 3.6.6

Trend in annual mean concentration of total phosphorus at stations (estuarine fjords /coastal and open parts of the inner marine waters) encompassed by the Nationwide Monitoring Programme for the period 1989–2000.

(Source: Henriksen et al., 2001).



Phytoplankton

Phytoplankton production depends on the input of nutrients and on light. Enhanced input of nutrients will thus increase primary production. Phytoplankton production in Danish marine water is generally high at present due to the high nutrient concentrations, although production has fallen over the past 25 years (*Figure 3.6.7*). During the second half of the 1990s, production was about 30% less than at the beginning of the 1980s.

The concentration of chlorophyll *a*, i.e. the pigment that plants use to absorb light, varies somewhat over the years. At the fjord and coastal stations, the chlorophyll *a* concentration increased until the mid 1980s, but has since been falling (*Figure 3.6.8*).

Compared with that in the fjords and coastal waters, the chlorophyll *a* concentration is considerably lower in the open inner marine waters as well as in the North Sea and the Skagerrak. The chlorophyll *a* concentration in the open parts of the inner marine waters was relatively constant during the period 1974–2000.

Oxygen deficit

The extent of oxygen deficit reflects the magnitude of nutrient loading, although the weather also plays an important role. The effects of oxygen deficit are numerous, including the development of a so-called "shroud" on the seabed formed by sulphur bacteria and extensive death of benthic invertebrates, especially in the fjords, as well as effects on the benthic vegetation, fish death (especially in nets and traps) and release of nutrients resulting in new algal blooms.

The unusually warm and calm late summer of 1997 caused widespread oxygen deficit in many fjords, including very severe oxygen deficit in Mariager Fjord. At the same time, however, low levels of nutrient loading in the two dry years 1996 and 1997 provided generally good oxygen conditions in the open marine waters. In 1998 and 1999, the level of precipitation and hence nutrient loading were high resulting in the reoccurrence of oxygen deficit in the open marine waters.

Oxygen deficit in 2001 was less serious than in 2000 and can be characterized as roughly average. Water runoff and nitrogen loading in the first half of the year did not deviate markedly from normal, and long periods of calm, warm weather did not occur. In many coastal waters, the changeable and periodically strong winds in summer and autumn resulted in relatively good oxygen conditions in 2001 (*Figure 3.6.9*).

From the mid 1970s to the end of the 1990s the autumn oxygen concen-

Figure 3.6.7

Trend in phytoplankton primary production in the Danish estuarine fjords for the period 1979–2000.

(Source: Henriksen et al., 2001).

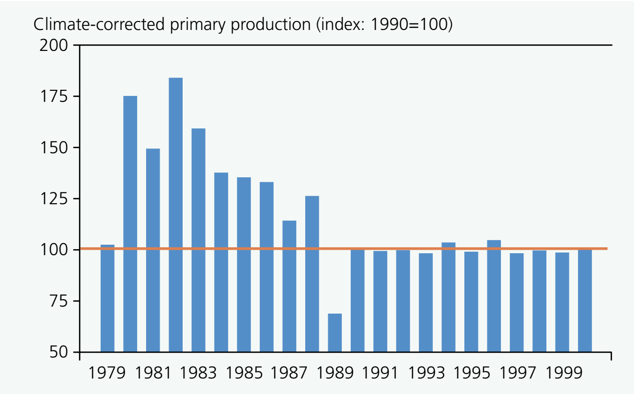
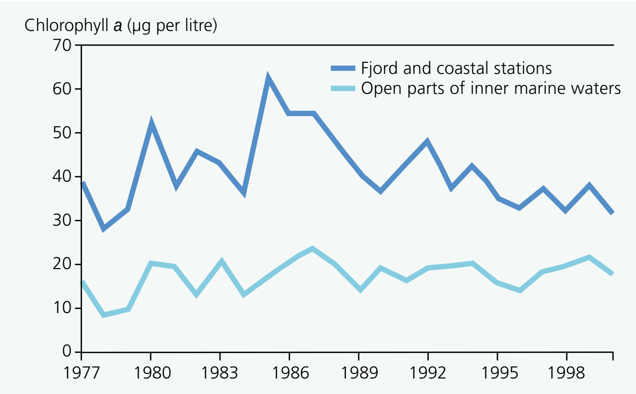


Figure 3.6.8

Trend in annual mean concentration of chlorophyll *a* at stations (estuarine fjords/coastal and open parts of the inner marine waters) encompassed by the Nationwide Monitoring Programme for the period 1989–2000 supplemented by earlier measurements for the period 1997–88.

(Source: Henriksen et al., 2001).



tration fell in the open waters of the Kattegat, the Øresund, the Great Belt and the Femer Belt (*Figure 3.6.10*). No clear trend has been detectable in oxygen conditions in the coastal waters, however, which are still relatively poor. Comparison of present data for the southern part of the Little Belt with that for the 1910s to the 1930s reveals that the area of seabed most frequently affected by oxygen deficit has increased almost five-fold.

Photo: Helene Munk Sørensen

Figure 3.6.9

Oxygen deficit map from September 2001 (Source: National Environmental Research Institute, 2001).

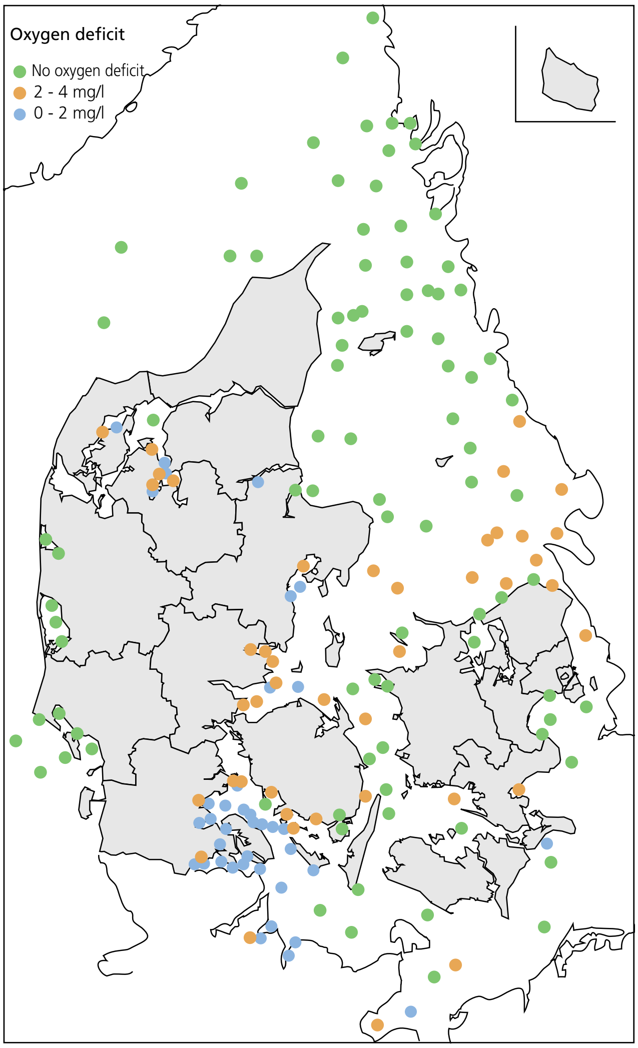


Figure 3.6.10

Trend in oxygen deficit in the sea. The figure shows the minimum oxygen content measured in the southern Kattegat each year over the period 1975–2000. The oxygen concentration is normally 8–10 mg O_2 per litre. Oxygen deficit is defined as an oxygen concentration below 4 mg per litre. (Source: National Environmental Research Institute, 2001).

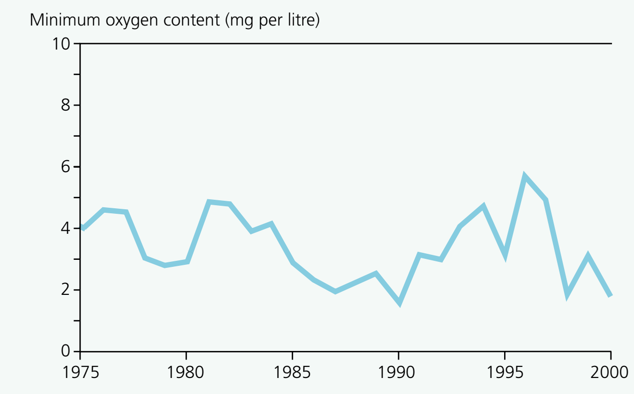


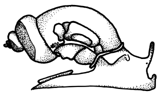
Photo: NERI/Signe Foverskov

3.6.2 Theme – harzardous substances in the marine and Arctic environments

The marine and Arctic environment is exposed to many different anthropogenic pressures, including inputs of hazardous substances and heavy metals. In the present context, hazardous substances are substances that are not naturally occurring in the environment, but which derive from human activities. The hazard they pose to the environment can be described through their toxicity, how easily they are taken up by living organisms (bioavailability), and whether they are stable and persistent.

Examples of hazardous substances include:

- Substances in the group polychlorinated halogenated aromatic hydrocarbons (e.g. PCB, HCH) are all very bioavailable and stable. PCBs are industrial chemicals no longer in use in Denmark. DDT and HCH were previously used as insecticides and are now banned in Denmark. Due to their stability, the substances are still present in the environment to some extent, and in some places still comprise a problem. New halogenated aromatic hydrocarbons have been developed such as the brominated flame retardants used in textiles, PCs, etc. Another group are the dioxins, which are formed upon combustion, and which are very bioavailable, stable and toxic.



- Many of the substances in the group polyaromatic hydrocarbons (PAH) derive from oil products and the combustion of oil products. Some of these substances can be formed naturally, but the majority of PAHs (approx. 75%) derive from oil spills directly into the sea from ships or oil pipelines.
- Antifouling agents, e.g. tributyl tin (TBT), are toxic substances that are applied to ship hulls in paint to prevent fouling by marine organisms. Fouling raises fuel consumption and reduces sailing speed. The use of certain antifouling agents on ships of less than 25 metres has been banned (TBT, Irgarol, Diuron), but other toxic products are placed on the market (Sea-nine, Zinc Omadine). Use of the old products is still permitted on large vessels. The International Maritime Organization is currently working for a total ban on TBT in 2008.
- Metals are naturally occurring in the environment. Increased inputs resulting from human activities have raised concentrations above the background levels, however. The heavy metals encompas such metals as cadmium, mercury, copper, lead and zinc. Of these, plants and animals need trace amounts of copper and zinc as micronutrients. At high levels, however, the substances are toxic (*Figure 3.6.11*).

Inputs

Many harzardous substances and heavy metals are contained in the products we use in our daily lives. The substances reach the marine environment through emissions during the production, use and disposal of the products. Hazardous substances and heavy metals reach the marine environment both via diffuse transboundary transport via sea currents, watercourses and atmospheric deposition, and via point sources such as wastewater treatment plants, separate industrial discharges and marine fish farms, marine disposal of harbour sediment and oil spills from ships and drilling rigs (*Figure 3.6.12*). Ship traffic also causes emission of combustion products to the air and release of antifouling agents to the sea.

Some inputs only have local or regional effects, for example in closed fjords or harbours. Other inputs of persistent substances are transported over long distances via marine currents, the atmosphere and ship traffic, and can affect large areas.

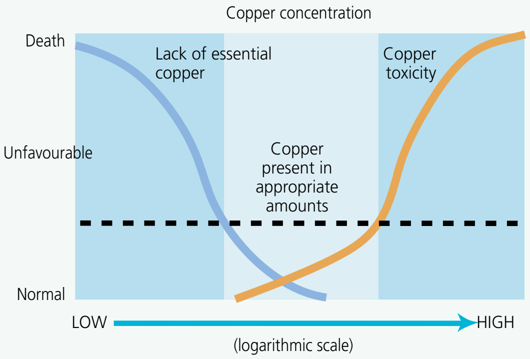


Figure 3.6.11

Copper is a micronutrient required by plants and animals, but which is toxic in high concentrations.

(Source: Foverskov et al., 1999).

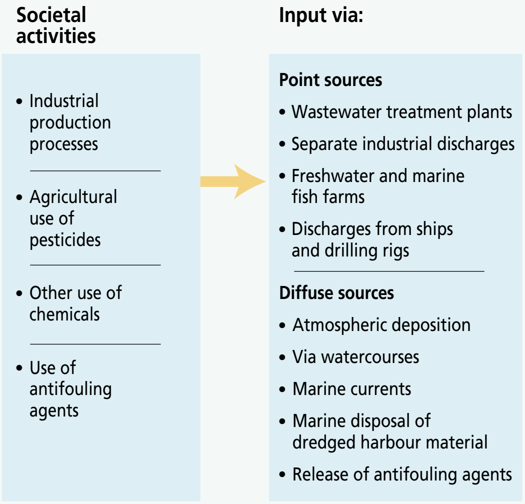


Figure 3.6.12

Anthropogenic sources and input of heavy metals and hazardous substances to the aquatic environment.

Distribution and uptake in the marine environment

The hazardous substances and heavy metals that are input to the sea are partly in dissolved form and partly bound to particles or organic matter in the water column. Aquatic organisms are therefore able to take up the hazardous substances both from the water phase and via their food. The majority of organisms, from bacteria to fish, can thus be affected. An example is the dispersal of copper from hull paint (*Figure 3.6.13*).

The particle-bound hazardous substances and heavy metals eventually sediment out on the seabed and become bound in the marine sediment. The concentration of the substances is often much higher in the sediment than in the water column. Moreover, the majority of the substances degrade more slowly in the sediment than in the water phase. Bacteria in the sediment and the benthic invertebrates are therefore considerably exposed to the substances. Since benthic invertebrates are the food resource of many fish species, the hazardous substances are taken up by fish. Many of the lipid-soluble, stable substances accumulate up the food chain. The same applies to other substances such as TBT, which particularly binds to proteins in the various links of the food chain (*Figure 3.6.14*). The concentration of TBT in eider is more than ten-fold greater than in common mussels, which are the eider's main food resource. Hazardous substances can also be released from the sediment and temporarily returned to the water column, for example by resuspension by strong winds, strong currents or changed oxygen conditions.

Effects of hazardous substances

Hazardous substances can have a variety of effects on the different parts of the marine environment. Some substances can cause hormonal disturbances and affect fertility, while others can affect the immune system and increase susceptibility to diseases. In addition, some hazardous substances affect metabolism and hence might affect growth. The same substance can have different effects on different organisms. For example, TBT affects metabolism in phytoplankton, while it affects sexual characteristics in gastropods.

We often do not become aware of the effects of hazardous substances until they affect higher animals

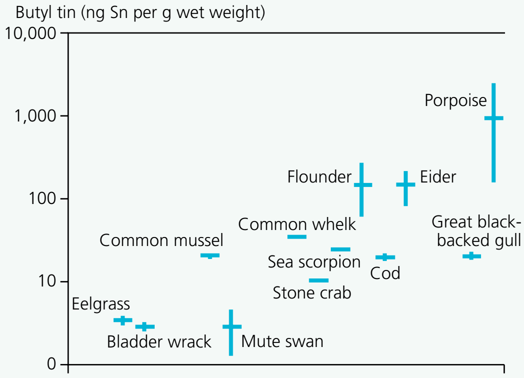


Figure 3.6.14
The TBT concentration increases the higher up the food chain one moves.
(Source: Foverskov et al., 1999).

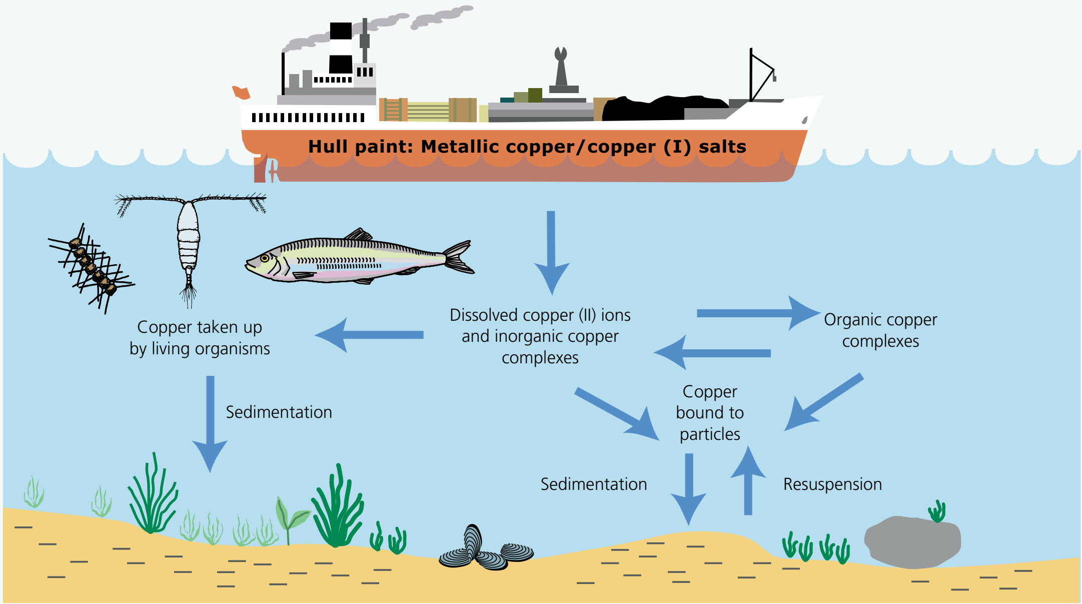


Figure 3.6.13
Example of the transport and occurrence of copper from hull paint in the aquatic environment. Dissolved copper(II) ions are the most toxic form of copper. When the copper ions become particle-bound, they are less toxic.
(Source: Foverskov et al., 1999).

such as birds of prey and seals. An example is the white-tailed eagle population in the Baltic Sea area, which was markedly affected by DDT and PCB in the period following 1950. The breeding success of the white-tailed eagle was very low in the 1960s, but has gradually improved as a result of the ban on the use of DDT, PCB and other hazardous substances.

It is often the case that when hazardous substances affect individual sectors such as fishery or affect human health, for example necessitating recommendations as to how much fish pregnant women may eat, society reacts with investigations and bans. The effects of TBT on oyster farming in France in the 1970s is thus the reason why a thorough investigation of TBT was undertaken, and why a total ban on its use in hull paints is now on the way.

Hazardous substances also affect algae, zooplankton and bacteria, but the effects are rarely as visible as on larger animals, and measurable effects are not observed until after long-term exposure. It is therefore difficult to monitor the effects on these organisms directly in the marine environment. Laboratory and field studies have provided some information about the effects however. The ecological structure and processes in many biological communities can thus have been affected for a long time before the effects of hazardous substances are registered. Ecotoxicological studies show, for example, that antifouling agents in the concentrations currently measured in the marine environment affect both the phytoplankton and bacterial communities. These communities are the key part of the marine ecosystem in that they are the precondition for the production of organic matter and the degradation of it.

Quality standards and objectives

The EEC Directive relating to the discharge of hazardous substances into the aquatic environment and the EU Water Framework Directive require environmental quality standards to be established for Danish marine waters, including environmental quality standards for hazardous substances and heavy metals. The possibility for establishing environmental quality standards for the individual substances depends on our knowledge about hazardous substances and heavy metals in the environment, including knowledge about sources, concentrations and effects on various organisms. The establishment of environmental quality standards is primarily useful when water quality has to be assessed, for example in connection with the issuance of discharge permits. The overall objective for the marine waters is a state with near zero concentrations of man-made synthetic substances and near background levels for naturally occurring substances.

Monitoring of hazardous substances and heavy metals in Denmark

Nationwide coordinated monitoring of hazardous substances and heavy metals in the marine environment was not initiated in Denmark until 1998 with the Danish Aquatic Environment Monitoring and Assessment Programme, NOVA-2003. This section is primarily based on the nationwide results of NOVA-2003 supplemented with further data from the Counties and other individual investigations.

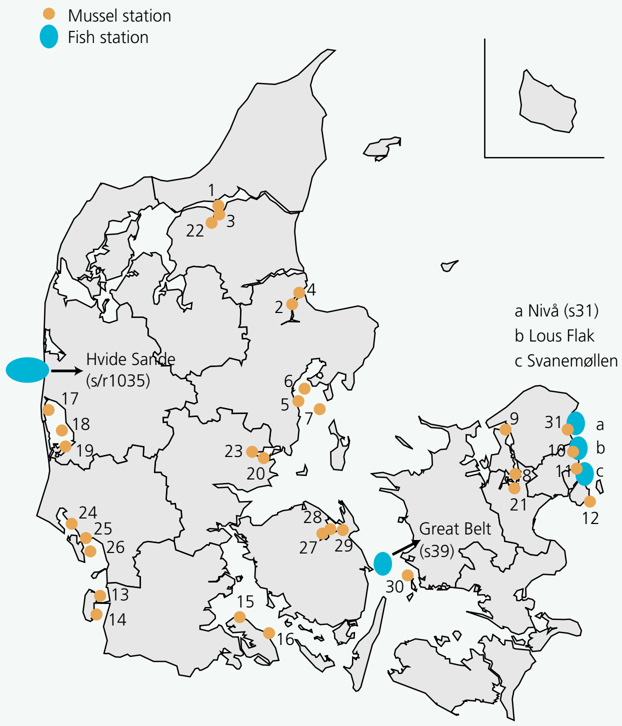
The measurement stations for hazardous substances and heavy metals encompassed by the monitoring programme are selected to represent polluted areas so as to facilitate assessment of the efficacy of measures to reduce discharges of hazardous substances and heavy metals (*Figure 3.6.15*). At point sources (large wastewater treatment plants, harbours and industrial enterprises), three stations have usually been established along a transect leading away from the source so as to enable determination of the distribution along a dilution gradient.

NOVA-2003 encompasses measurement of heavy metals (Zn, Cu, Ni, Hg, Cd and Pb), polychlorinated hydrocarbons (PCBs, HCH and DDT), polyaromatic hydrocarbons (PAHs) and the antifouling agent tributyltin (TBT) and its degradation products.

Figure 3.6.15

Map of Danish Aquatic Monitoring and Assessment Programme (NOVA-2003) stations at which heavy metals and hazardous substances are measured.

(Source: Hansen et al., 2000).



Classification of hazardous substances and heavy metals

Box 3.6.3
Classification of hazardous substances and heavy metals.

The observed concentrations have to be assessed in relation to the natural background levels and the expected environmental effects of the substances. As it is difficult to measure effects directly in the environment, a number of classification methods are used to assess the occurrence and effects of these substances in the environment. A common feature of these classification methods is that a given area is assigned a quality class based on how clean the area is. However, the classification methods are not unambiguous as regards the definition of the cleanest quality class (reference state), number of classes and the subdivision into quality classes.

Sweden and Norway have introduced quality classes based on measured concentrations of heavy metals and organic pollutants. The two countries' classification methods differ, though, in that the cleanest class (Class 1) has been set to a concentration of zero in the Swedish classification, whereas the Norwegian Class 1 is defined on the basis of areas that only receive diffuse inputs of a given substance. The Swedish and Norwegian classification methods do not take into account at which concentrations the substance can be expected to have an effect on the environment.

In addition to measurement of the concentrations of the investigated substances, such an ecotoxicological assessment is incorporated in the OSPAR ecotoxicological assessment criteria (EAC). When establishing EACs, the substance is tested on at least three different species in order to determine its toxicity. If information is available on societal or ecosystem effects, this can also be included in the assessment. EACs have to be used together with the OSPAR Joint Assessment and Monitoring programme (JAMP) as a tool for determining to what extent the substances can be considered to have potential impacts on the marine environment. Within the OSPAR framework, EACs are determined from published effect concentrations divided by a factor of 10 to 10,000 depending on whether the value is an EC_{50} (50% effect concentration) or a NOEC (no effect concentration) (*Figure 3.6.16*). The reliability of an EAC for a given substance increases in line with both the number of studies and the number of marine organisms included in the assessment. Due to uncertainty of the measurements, EACs have not yet been determined for heavy metals in biota.

The marine toxicity of a hazardous substance is usually investigated by laboratory experiments in which various amounts of the substance are added to the water followed by determination of the concentration that kills half of the test organisms within 48–96 hours, the so-called lethal concentration or LC_{50}. One can also determine the lowest concentration at which the first organisms die (LOEC) or the highest concentration at which none of the organisms die (NOEC). These tests necessitate prolonged investigation, however. Instead of mortality, one sometimes measures other effects, e.g. influence on growth. In that case, one refers to effect concentration, or EC_{50}.

No corresponding classification presently exists in Denmark, but the Water Framework Directive requires that such a classification be drawn up. The Danish classification is expected to be based on ecotoxicological assessment criteria.

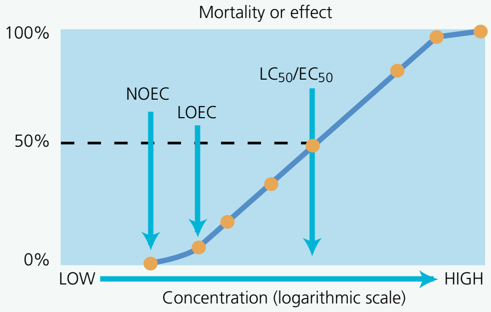


Figure 3.6.16
Mortality or effect.
(Source: National Environmental Research Institute, 1999).

Table 3.6.1
Various criteria for hazardous substances and heavy metals in sediments.

Substance/criteria (mg per kg dry weight)	Norway Quality Class I	Sweden Reference Quality	OSPAR EAC (provisional)
Cu	<35	15.0	5-50
Cd	<0.25	0.2	0.1–1
Pb	<30	25.0	5-50
Sum PCB	<0.050	0	0.001–0.01
Benzo(*a*)pyrene	<0.005	0	0.1–1
TBT	-	0	0.000005–0.00005

Hazardous substances and heavy metals are measured in mussels each year and in sediment every third year. Heavy metals are also measured each year in fish from Hvide Sande and Nivå Bay. The mussel, fish and sediment measurements are so-called integrated samples as they record the concentration levels over a long period prior to sampling. Water samples are collected every second year for analysis of certain organic substances. These samples yield the concentrations of the selected organic substances at the moment of sampling.

The effects of TBT on marine gastropods are assessed by investigating their sexual organs once a year. The majority of the marine gastropods in Danish waters are unisexual. In female gastropods, TBT affects the balance between male and female sex hormones with the result that male sex hormone accumulates in the female gastropods. In addition to their normal female characteristics such as ovaries, egg sacks and genital opening, the female gastropods therefore also develop a penis and spermatic ducts. The phenomenon is termed imposex.

Inputs of heavy metals

The main sources of heavy metal inputs to Danish marine waters are point sources (wastewater treatment plants and industry), watercourses and deposition from the atmosphere (*Figure 3.6.17*). In addition, copper is input from antifouling paints and cadmium from sacrificial anodes (used for corrosion protection of iron and steel structures, especially in water on ships and in harbours).

Over the past 20–25 years there has been a marked decrease in consumption of products and production processes in which heavy metals are used. For example, the use of mercury in the production of chlorine and the production of phosphoric acid entailing the discharge of cadmium ceased 10 and 20 years ago, respectively. Other measures such as filters on outlets from dental clinics that retain mercury from dental fillings, or flue gas abatement at power stations and waste incineration plants have also reduced discharges to the environment.

Many measures have been introduced to reduce the heavy metals content of products. Marked reductions have been achieved with the three most toxic metals: Mercury, cadmium and lead. For example, the mercury content of products is presently very low, the cadmium content of plastic and phosphorus fertilizer has been reduced considerably, and the addition of lead to petrol has been phased out.

In general, Danish emissions to the air are considerably less than the estimated deposition on the inner marine waters (*Table 3.6.2*). Part of the deposition must

	Arsenic tonnes	Lead tonnes	Cadmium kg	Chromium tonnes	Copper tonnes	Mercury kg	Nickel tonnes	Zinc tonnes
• Danish emissions to the air	0.85	7.3	713	2.7	9.60	1976	15.2	23
Atmospheric deposition	6.00	48	1,600	7.0	46.00		9.0	360
• Wastewater treatment plants	8.60	1.7	570	2.1	5.50	460	12.0	70
• Separate industrial discharges	0	0.07	4	0.2	0.35	2.3	0.4	0.6
• Sparsely built-up areas	0.03	0.2	30	0.2	1.00	20	0.5	4
• Riverine*	14.30	13.2	670	16.8	37.00	59	49.0	145
Point-source and riverine inputs	20.00	14.3	1,050	18.2	40.70	366	57.0	192
Other inputs:		100-150**	600***		18-28****			

* Riverine is calculated on the basis of 4 major watercourses extrapolated to the total area of Denmark: includes contributions from some point sources.

** Lead (1985): 100–150 tonnes of lead are estimated to be lost annually with fishing gear (nets, seines, sinkers).

*** Cadmium (1996): 600 kg of cadmium are estimated to be discharged annually from sacrificial anodes.

**** Copper (1992): An estimated 18–28 tonnes of copper are discharged annually from antifouling paints.

Table 3.6.2
Input of heavy metals to Danish marine waters in 1999.
(Source: National Environmental Research Institute, 2000; Hovmand and Kemp, 2000; Danish Environmental Protection Agency, 2000; Bøgestrand, 2000).

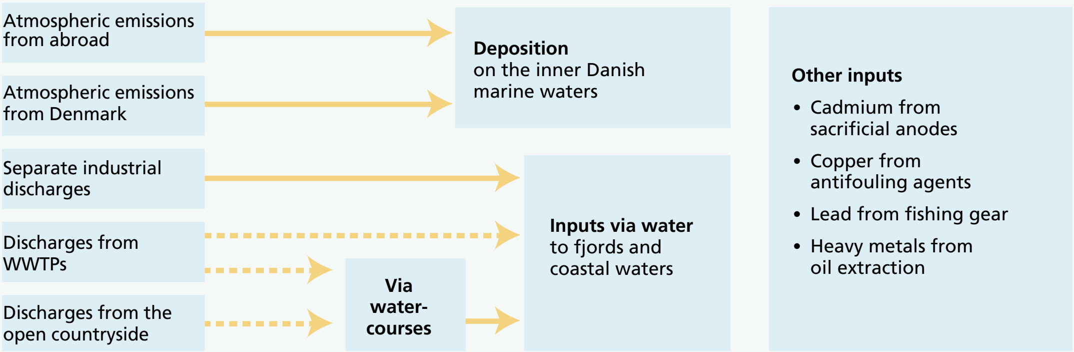


Figure 3.6.17
Input of heavy metals to the Danish marine waters.

therefore derive from abroad. In the case of lead and zinc, input via atmospheric deposition is somewhat greater than riverine and point source inputs. Conversely, riverine and point-source inputs are the most important in the case of arsenic, chromium and nickel. Considerable inputs of lead, cadmium and copper also derive from fishing gear, sacrificial anodes and antifouling paints, respectively.

The most important sources of heavy metal emissions to the air are combustion of fossil fuels and waste. Between 1990 and 1999, emissions of heavy metals fell markedly. The reduction ranged from 4% for copper to 94% for lead (*Table 3.6.3*). The reduction in emissions is largely due to increased cleaning of flue gasses at power plants and district heating plants, including waste incineration plants. With lead, the fall is largely due to the introduction of unleaded petrol. The reduction in the emission of heavy metals is clearly reflected by a reduction in the deposition of heavy metals over the past ten years. The change is greatest for lead, the deposition of which has fallen five-fold. Deposition of zinc and copper have been roughly halved.

Over the past 15 years, wastewater treatment plants have been upgraded to include phosphorus stripping. The process also retains a large part of the hazardous substances and heavy metals. In 1999, more than half of the heavy metals led to the wastewater treatment plants were retained (*Table 3.6.4*).

Input of hazardous substances

The hazardous substances entering the marine waters derive in part from household and industrial use of chemicals. A large part of the substances in wastewater are retained in the wastewater treatment plants, while some of the substances are discharged into the aquatic environment. Analyses carried out at Roskilde WWTP of the inflow and outflow concentrations of three substances – phthalates and nonylphenols, both of which have hormone-like effects, and the anionic detergent LAS – revealed that between 85% and 99% of the substances was retained by the plant. The majority was degraded, and only between 15% and 35% of the inflow content reappeared in the sewage sludge from the plant (*Figure 3.6.18*).

Table 3.6.3 (upper)
Danish emissions of heavy metals to the air
in 1990 and 1999.
(Source: National Environmental Research Institute, 2000).

Table 3.6.4 (lower)
Mean inflow and outflow concentrations of heavy
metals at 19 selected wastewater treatment plants
and calculated percentage retention in 1999.
(Source: Danish Environmental Protection Agency, 2000).

(1,000 kg)	**Arsenic**	**Lead**	**Cadmium**	**Chromium**	**Copper**	**Mercury**	**Nickel**	**Zinc**	**Selenium**
1990	1.4	127.0	1.1	6.2	10.0	3.2	26.5	34.6	4.2
1999	0.8	7.3	0.7	2.7	9.6	2.0	15.2	22.9	3.5
Reduction (%)	42.0	94.0	37.0	57.0	4.0	38.0	43.0	34.0	17.0

Concentration (µg/l)	**Arsenic**	**Lead**	**Cadmium**	**Chromium**	**Copper**	**Mercury**	**Nickel**	**Zinc**
Inflow	2.3	13.0	0.5	9.0	8.0	0.5	12.0	24.0
Outflow	1.2	2.6	0.2	1.8	7.2	0.2	8.2	105.0
Retention (%)	48.0	80.0	60.0	80.0	92.0	60.0	32.0	58.0

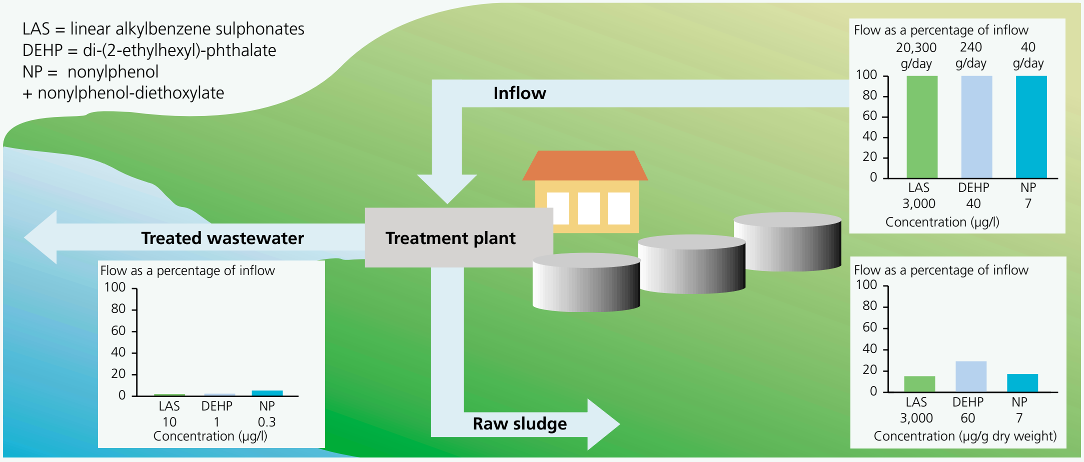


Figure 3.6.18
Concentrations and flow of selected hazardous substances in the inflow to and outflow and sludge from a wastewater treatment plant in Roskilde (Bjergmarken).
(Source: Fauser et al., 2001).

Some of the pesticides we use also enter the aquatic environment (*see Section 4.5*). Extraction of oil and natural gas, including the use of production chemicals, also leads to the discharge of hazardous substances into the marine environment (*see Section 1.3.1*).

Any object in the sea will become fouled by growths within a short time, irrespective of whether the object is a bridge pier, a wooden stake or a ship. In the latter case the consequence is that the hull becomes less smooth, thereby increasing water resistance during sailing. If the growths form on the ship's rudder, the ship's manoeuvrability can be reduced too. The result for the ship is lower speed and greater fuel consumption. In both cases there are both economic and environmental consequences.

Attempts have been made to protect ship hulls from fouling ever since ancient times. Modern hull paints nearly all contain copper in one form or another. In addition, they contain one or more toxic antifouling agents. The most effective antifouling agent is tributyl tin (TBT). When a treated vessel floats in the water, the toxic substances are released from the hull paint and form a thin membrane coating the hull. In close proximity to the hull the concentration of the toxin will be very high. Organisms that attempt to attach themselves to the hull will be killed before they can do so.

At the beginning of the 1980s, following approx. 20 years of use of TBT, it was found that the substance had a number of unexpected side effects. The use of TBT on ships of less than 25 metres was therefore banned in Denmark in 1991. TBT may still be used in hull paint for major vessels such as ferries, tankers and large trawlers. The International Maritime Organization is about to prohibit the use of TBT from 2003 and the presence of TBT on ships from 2008.

Heavy metals in the aquatic environment

Aarhus County has measured the concentrations of heavy metals in sediment cores from Aarhus Bay, Mariager Fjord and elsewhere and found that they had increased 3–8 fold relative to the levels in the 18th century. Around 1990, the concentrations of some of the metals started to fall.

Measurements made under NOVA-2003 show that the concentration of mercury is highest in the Øresund from Nivå to south of Amager, in the Wadden Sea at Rømø and in Randers Fjord (*Figure 3.6.20*). These findings are in good agreement with the fact that the Øresund has been subjected to high levels of mercury loading from both Danish and Swedish chemicals industry over the past 100 years. Sediment from Copenhagen harbour in particular contains large amounts of mercury chiefly derived from the former production of chlorine. The mercury accumulated in the sediment is thus the cause of the high mercury concentrations in mussels. The high levels of mercury in the Wadden Sea are undoubtedly attributable to the relatively high levels of mercury loading via the major rivers that run into the North Sea, including the Elbe and the Weser.

The concentration of mercury in mussels from unpolluted areas of Greenland are surprisingly of the same level as in Denmark, even though one would expect mercury pollution in Greenland to be considerably lower

Figure 3.6.19

Estimated amounts of various toxic substances released into Danish marine waters from ship hulls. A medium-size tanker of 100 metres can contaminate 100,000,000,000 litres of seawater per day.

(Source: Foverskov et al., 1999).

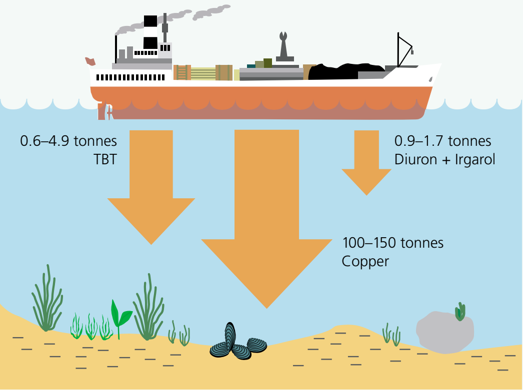
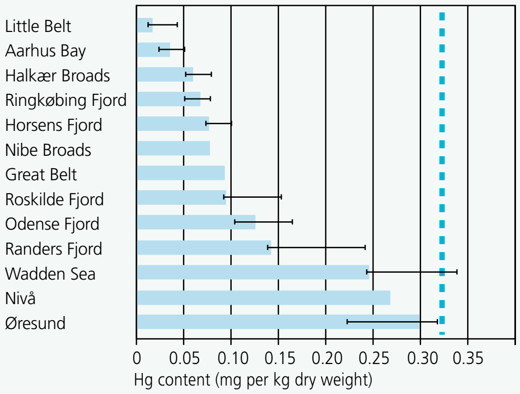


Figure 3.6.20

Mercury (Hg) content of mussels. The broken line indicates the Norwegian limit level for Quality Class 1. The corresponding values for Greenland (in mg Hg per kg dry weight) are: Qeqertarsuaq (Godhavn): 0.090; Nanortalik: 0.12; Uummaannaq: 0.092.

(Source: National Environmental Research Institute, 2000).



than in Denmark. The explanation must be that mussels grow much more slowly in Greenland than in Denmark. They have therefore had a longer time, and possibly also a greater metabolism relative to growth, to accumulate mercury from their food.

The concentration of cadmium is highest in Randers Fjord and Ringkøbing Fjord (*Figure 3.6.21*). The cadmium concentration in common mussels from Greenland is clearly higher than in Denmark, probably due to the slow growth in the cold water.

The concentration of lead in Danish mussels is generally less than 1 mg per kg dry weight, with slightly higher concentrations in the Øresund region. Despite the fact that anthropogenic lead pollution cannot be expected in Greenland, the lead concentration in mussels there is similar to that in Denmark, probably for the same reason given for mercury and cadmium.

The highest mercury and cadmium concentrations measured exceed Quality Class 1 in the Norwegian classification. In contrast, the measured lead concentrations are all lower than the limit for Class 1.

The cadmium concentration in fish varies considerably from year to year, but the trend since 1978 is towards a slight increase. This applies to fish from both the east coast and west coast of Denmark (*Figure 3.6.22*). A similar trend is seen for whitebait from the Swedish east coast. The cause of the increasing cadmium concentrations is unclear.

Hazardous substances in the aquatic environment

The antifouling agent TBT and its degradation products occur in mussels at all stations (*Figure 3.6.23*). The highest concentrations are found in harbours and areas where ship traffic is intensive such as Odense Fjord, Øresund and Aarhus Bay. The OSPAR Ecotoxicological Assessment Criteria (EAC) for TBT is 1–10 µg per kg dry weight. The majority of TBT concentrations measured in mussels exceed the EAC value – often greatly – and environmental effects must therefore be expected.

NOVA-2003 encompasses monitoring of hormonal disturbances in various species of marine gastropods. TBT can cause sexual changes in marine gastropods in

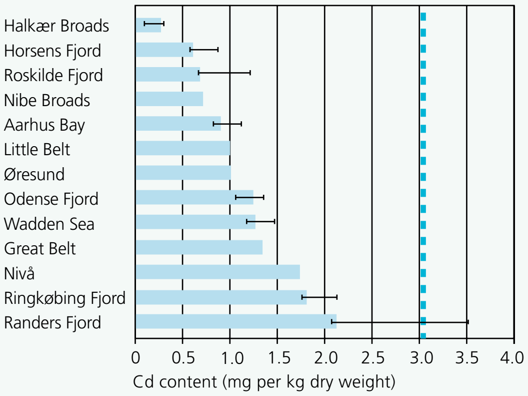


Figure 3.6.21

Cadmium (Cd) content of mussels. The broken line indicates the Norwegian limit level for Quality Class 1. The corresponding values for Greenland (in mg Cd per kg dry weight) are: Qeqertarsuaq (Godhavn): 5.04; Nanortalik: 3.75; Uummaannaq: 3.55.

(Source: National Environmental Research Institute, 2000).

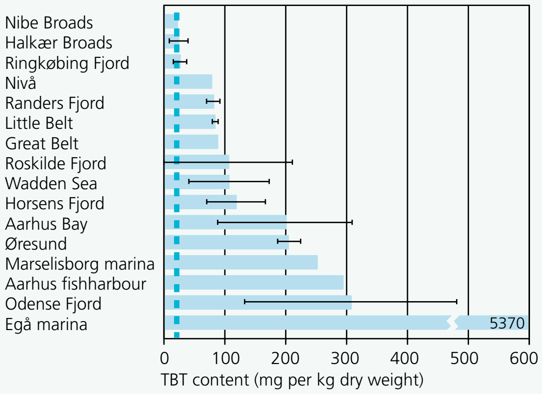


Figure 3.6.23

TBT content of mussels. Around Nuuk (Godthåb) the concentration detected was between 1.2 and 7 µg TBT per kg dry weight, reflecting the lower level of marine traffic and the high degree of dilution.

(Source: Hansen et al., 2000).

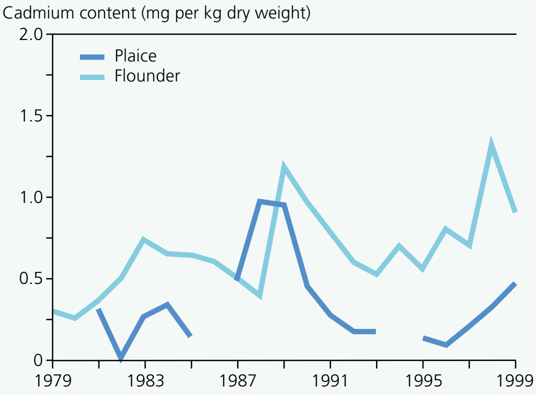


Figure 3.6.22

Cadmium (Cd) content of liver in flounder from the Øresund and plaice from the North Sea (Hvide Sande).

(Source: Hansen et al., 2000).

the form of irreversible development of visible male sexual characteristics in otherwise unisexual female gastropods, a phenomenon termed imposex. Investigation of imposex in dwarf whelk has revealed clear gradients radiating from the major harbours in Horsens Fjord, the Øresund at Copenhagen and Aarhus Bay (*Figure 3.6.24*). Imposex occurs in the majority of the gastropods in an area 0–4 km from the harbours, and usually in advanced stages. The occurrence of imposex is even increased 5–17 km away from the harbours compared with that in Hevring Bay, which lies 23–25 km from Randers harbour, and where less than 5% have developed imposex. This low level must be considered the background level of imposex in the inner Danish marine waters.

Since the 1970s, it has been forbidden to use PCB and DDT in Denmark and elsewhere in Western Europe. Since the introduction of the ban, the concentrations of PCB and DDT have fallen. The substances are still found in mussels at all the monitoring stations encompassed by NOVA-2003, however. The PCB concentration exceeds the lower EAC limit of 1 µg per kg wet weight, but does not exceed the Norwegian Quality Class 1 of 10 µg per kg wet weight. It should be noted that the PCB values measured under NOVA-2003 are based on ten PCBs and hence are not directly comparable with the EAC values, which are based on only seven PCBs.

There are some indications, though, that some diffuse input still takes place via long-range atmospheric transport from other countries where PCBs are still in use, e.g. Russia. The relationship between “old” and “new” PCB concentrations has been calculated in fish from the Baltic Sea and the Kattegat since the end of the 1980s. The ratio has been falling, but in the last 3–4 years has remained unchanged or has increased, thus indicating the input of new PCB.

Polyaromatic hydrocarbons (PAHs) are also found at all monitoring stations, in most cases in concentrations exceeding the Norwegian Quality Class 1. It should be noted, though, that NOVA-2003 encompasses measurement of more PAHs than the standard requires. High molecular weight PAHs, e.g. anthracene, are classified as carcinogens, while low molecular weight PAHs, e.g. benzo(*a*)pyrene, are acutely toxic to marine animals.


Photo: NERI/Jan Damgaard

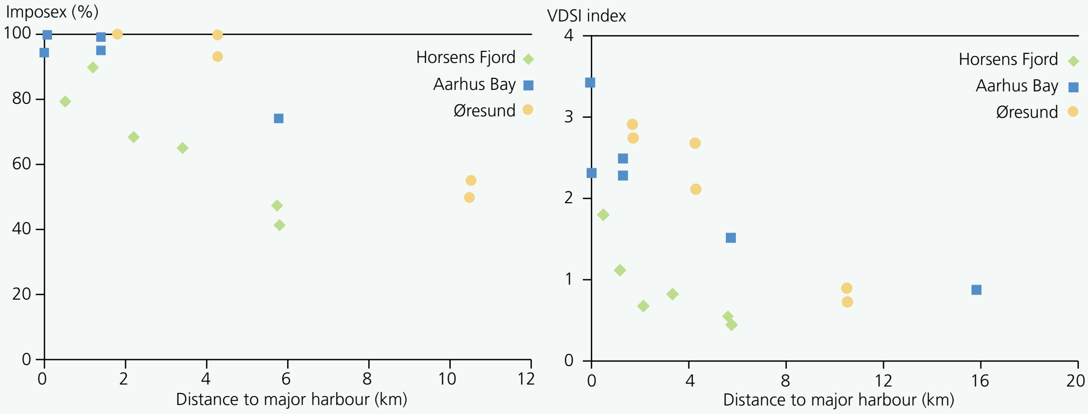


Figure 3.6.24

Relationship between imposex in dwarf whelk (*Hinia reticulata*) and distance to the nearest major harbour in various coastal waters. The occurrence of imposex is expressed as the percentage of females with imposex and the degree of development of imposex as a VDSI index where fully developed imposex has a VDSI value of 4. (Source: Hansen et al., 2000).

In several areas the lower EAC limit for anthracene is also exceeded, and in the outer part of Roskilde Fjord the upper EAC limit of 10 µg per kg wet weight is exceeded. The benzo(*a*)pyrene concentration is higher than the Norwegian limit value at all stations.

PAHs are suspected of negatively affecting fish. Swedish studies show, for example, that levels of detoxifying enzymes have increased in fish over the past ten years, thus indicating that the pressure from hazardous substances has increased. This is despite the fact that the concentration of most of the known substances (PCBs, DDTs) have decreased during the same period. PAHs have been spotlighted as a possible cause.

Heavy metals and hazardous substances in Greenland

Virtually all of the measured hazardous substances have also been detected in the environment of Greenland.

The substances of greatest interest are mercury and the chlorinated hydrocarbons such as PCB and DDT. Pollutants in the marine environment around Greenland derive from sources inside and outside the country. The substances are transported to Greenland via the atmosphere and sea currents, or derive from sources inside the country. The relative significance of the various transport pathways is not fully known, but there is no doubt that anthropogenic pollution mainly derives from sources outside Greenland. Sources inside Greenland only have a local impact, especially in areas where mining has taken place. Unregulated landfills in the towns and settlements and waste incineration have caused local marine pollution. The effects of this have never been studied systematically, though, as they are expected to be very local and of relatively minor significance as there are no major industries in Greenland.

The main sources of pollution in Greenland are the metal mines in Mestervig, Ivittuut and Maarmorilik. Lead and zinc pollution of the sea is and has been the worst environmental problem at these mines. The fjords have been polluted with lead up to 40 km away from the mines. The pollution has continued after closure of the mines, moreover, although the levels have been steadily falling. The sources of the pollution are discharged mining waste, abandoned rock heaps containing lead and zinc residues, spillage of metal concentrate, and finely crushed mineral particles spread as dust.

Natural factors also play a role. Thus, the mercury content of many of the marine dietary products (fish, seals, etc.) is naturally high. Moreover, studies of marine sediments, etc. show that around half of the mercury presently found in the environment is natural in origin. The other half appears to be the result of human activities outside Greenland and mainly derives from atmospheric deposition. Part of this derives from Europe, for example from the use of mercury-containing products and production processes, the combustion of coal and the incineration of waste. Mercury emissions to the air are generally falling, but considerable amounts of mercury still reaches the Arctic region.

Cadmium concentrations in certain sea birds and marine mammals in Greenland are so high that kidney damage could be expected in these animals. Such effects have not yet been demonstrated, however. The effect of mercury in Greenlandic animals is difficult to assess as all animals with a high content of mercury also have a high content of selenium, which is presumed to detoxify mercury.

The levels of lead and mercury in hair and lead in bone are higher in present-day Greenlanders than in the 500-year-old mummies found near Uummannaq. The concentration of mercury, especially methyl mercury and certain chlorinated compounds in the traditional Greenlandic diet is so high that effects on health cannot be ruled out.

Oil exploration in the marine waters of western Greenland in the last few decades has mainly consisted of seismological surveys, and only a single test well has been drilled. Compared with the Danish part of the North Sea, the amounts of hazardous substances discharged are very small due to the limited extent of the activities.

The level of persistent organic pollutants (POPs) in the food chains in Greenland cannot be explained on the basis of local sources. The most rapid, most significant and most direct transport pathway is atmospheric deposition. Much PCB seems to be transported to Greenland from Europe by sea currents, though, and transport via the major Russian rivers, sea ice and the atmosphere also play a role. The concentration of these substances is characteristically higher in eastern Greenland than in western Greenland, for example in seals.

Polar bears are uppermost in the food chain and therefore take up relatively large amounts of the lipid-soluble hazardous substances (POPs) via their food, which mainly consists of seal blubber. Since 1990, ten female polar bears have been found on Svalbard with alterations in their external genitalia – so-called pseudohermaphrodites, in which the clitoris is enlarged. Polar bears on Svalbard and in eastern Greenland have the highest POP levels among the polar bears of the world, and high POP levels are suspected of having provoked these alterations.

A study of the possible effect of POPs on the external and internal organs of polar bears in eastern Greenland was initiated in 1999. The studies, which are being conducted in collaboration with hunters from Ittoqqortoormiit, Scoresbysund and Ammassalik municipalities, include three main elements:

- Collection of information from polar bear hunters from eastern Greenland on the occurrence of polar bears, in particular on the occurrence of changes (visible deviations from normal, e.g. disease) and on the polar bear catch
- Investigation of bones (skulls and penis bones) and organ/tissue samples from 100 polar bears caught by hunters in Ittoqqortoormiit municipality during the period 1999–2001
- Comparison of the occurrence of changes in historical samples and newly collected samples of skulls and penis bones from eastern Greenland.

Photo: Foxtrot/Steen Andersen

Polar bear hunting in eastern Greenland. The photograph shows four hunters from Scorebysund on a polar bear hunt in March 2000. The almost four-week long hunting trip yielded two polar bears. Samples were collected from both animals for the polar bear studies.

Photo: Unknown

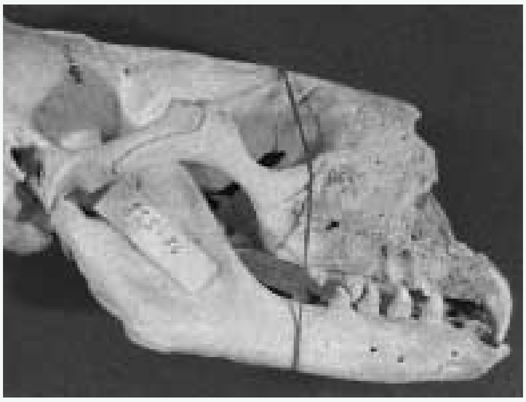


Photo: Unknown

Polar bear skull. These are interesting to investigate because several studies indicate that mammals under stress (for example as a result of POPs in the environment) can develop brittle bones, which can be revealed by radiological examination of the skull.

Summary and future initiatives

The sea is often the final recipient of many hazardous substances and heavy metals, irrespective of where the sources are located. It is worrying that many of the hazardous substances are detected in Greenland despite the fact that the sources are far away. Long-range transport of persistent pollutants may be one of the reasons why substances such as PCB and DDT, which have been banned in most Western countries for the past 25 years, are still present in the environment.

Most discharges from point sources such as wastewater treatment plants and industrial plants are now regulated. The introduction of cleaner technology in industrial production processes and limitation of the use of the most harmful substances have reduced inputs of many of the substances. Regulating and limiting inputs from diffuse discharges such as combustion of coal, incineration of waste, and riverine runoff are far more difficult, however. As the inputs are often dominated by diffuse discharges, it is necessary to make a major effort to control these sources. One obvious way is to limit consumption of chemicals and thereby limit input to the environment.

Another type of source that should be controlled is the areas that are very contaminated by old discharges, e.g. harbours and old industrial sites. Substances from these areas spread elsewhere in the environment via diffuse pathways and by marine dumping of harbour sediment.

The concentrations of many hazardous substances and heavy metals in the Danish marine environment exceed levels consistent with good environmental quality. In certain cases the concentrations are so high that effects can be expected on the flora and fauna. Fjords and coastal waters receiving discharges from large towns and areas with industrial activity and ship traffic are particularly badly affected.

The majority of the substances encompassed by the monitoring programmes are those that have already been acknowledged as posing threats to the marine environment. Monitoring improves our knowledge of their concentrations in Danish marine waters, thereby better enabling us to assess their environmental effects and hence determine which substances need to be regulated.

Examples of new substances for which our knowledge is presently inadequate include:

- Brominated flame retardants, which are present in the marine environment and in breast milk
- Bactericides such as triclosan, which is used in cleaning agents and toothpaste, has been detected in fish near wastewater treatment plants in Sweden
- Hormone-like substances, the impacts of which have been demonstrated in inland waters (*see Section 3.4*)
- PFOS (perfluorooctanyl sulphonic acid) wood preservative. PFOS causes reproductive damage in the second generation of rats exposed to the substance. In addition, much indicates that PFOS is also very persistent in the environment and has a tendency to accumulate in human and animal tissue. At the same time, the substance has been detected in several human blood samples and in birds that feed on fish – including in samples from some that have never been in contact with the substance. The American sole manufacturer of the substance, 3M, has begun to phase out the substance globally, and the Danish EPA has initiated an investigation of PFOS in Danish products and marine sediments.

Oil exploration activity in Greenland has increased, thus opening up the possibility of oil production, even though the latest test wells have yielded negative results. Oils spills are difficult to deal with in icy marine waters and pose a particular risk for seabird populations and coastal resources such as ammassat (a codfish) and lumpsucker. The large amounts of radioactive waste that are stored in northern Russia comprise a threat to the whole of the Arctic and especially to Greenland due to the eastern Greenland current, which runs south along the east coast of Greenland.

According to the EU Water Framework Directive, the environmental state of surface waters is to be expressed in terms of status classes with associated environmental quality standards. The OSPAR ecotoxicological assessment criteria (EACs) could serve as the basis for these quality standards. EACs have only been established for a few substances, however. The general problem with determination of status classes is that information is lacking on nearly all of the substances. In future, there will be an increased need to integrate information on inputs, concentrations and effects of hazardous substances in the monitoring programme.


Photo: NERI/Peter Bondo Christensen

3.7 Objectives and selected measures for the aquatic environment area

The overall objective is to ensure that the water in Denmark is clean. The quality and protection of the aquatic environment is accorded high priority – both nationally and internationally. At the EU level the policy is established by the Water Framework Directive, which is to be implemented in Danish law. The overall purpose of the Directive is to protect inland surface waters, transitional waters (estuaries, etc.), coastal waters and groundwater by:

- Preventing further deterioration and protecting and enhancing the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems
- Promoting sustainable water use based on long-term protection of available water resources
- Enhancing protection and improvement of the aquatic environment, *inter alia*, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of priority hazardous substances
- Reducing and preventing pollution of groundwater
- Mitigating the effects of floods and droughts.

The Water Framework Directive establishes a number of specific environmental objectives. One of the fundamental objectives is that Member States shall prevent deterioration of the status of all bodies of surface water and groundwater. Surface waters and groundwater are to be restored with the aim of achieving good status no later than 15 years after the Directive entered into force. For surface waters, good status means that both the ecological status and chemical status can be characterized as good – among other things that habitat conditions for plants and animals are good. For groundwater, good status means that the available groundwater resource is not exceeded by the long-term rate of abstraction, and that its chemical status is good.

These objectives entail that only insignificant or minor anthropogenic changes in the status of the aquatic environment are acceptable.

The work to ensure a cleaner aquatic environment is largely based on thematic or sector-specific action plans and strategies, among others the first and second Action Plan on the Aquatic Environment (*see Section 3.8*), the Ten-point Programme to Protect the Groundwater and the Pesticide Action Plan (*see Section 4.5*), and the Action Plan to reduce ammonia volatilization from agriculture (*see Section 2.4*). The sector and thematic action plans hold a central position in the development of policies and strategies for protection of the aquatic environment. It is here that the environmental objectives are concretized, and political agreements are reached on future environmental initiatives.

The environmental objectives established and the effectiveness of the measures implemented are regularly assessed on the basis of County supervision of water bodies and the Danish Aquatic Monitoring and Assessment Programme (NOVA-2003), as well as other supervision and monitoring activities.


Photo: DFNA/Bent Lauge Madsen

3.8 Theme – Midterm evaluation of Action Plan on the Aquatic Environment II

On 17 February 1998, the Danish Parliament adopted the follow-up to the Action Plan on the Aquatic Environment – Action Plan on the Aquatic Environment II. This is the latest in a series of action plans aimed at protecting the Danish aquatic environment against nutrient pollution. The objective of the Action Plan is to reduce annual nitrogen leaching from cultivated land by 100,000 tonnes N, thus reiterating one of the objectives of the earlier action plans. The Action Plan encompasses a broad range of measures that have to be implemented before the end of 2003.

The political agreement on Action Plan on the Aquatic Environment II (hereafter referred to as the Action Plan) stipulated that a midterm evaluation of the plan should be carried out at the end of the fertilization year 1998/99 to determine the expected total reduction in annual nitrogen leaching by the end of 2003 relative to the reduction target of 100,000 tonnes. The midterm evaluation had to encompass such aspects as the trend in consumption of commercial fertilizer as an indicator and the effects of the Agenda 2000 reform of EU Common Agricultural Policy. The purpose of the midterm evaluation was to provide politicians with a scientific basis for assessing the need to adjust the measures in the Action Plan.

The parties to the agreement reviewed the midterm evaluation during the first few months of 2001, and on 26 April 2001 entered into an agreement to adjust the measures in the Action Plan so as to maximize the likelihood that the reduction target would be attained by the end of 2003.

3.8.1 Background for Action Plan on the Aquatic Environment II

The period 1960 to 1985 was characterized by marked growth in agricultural production and imports of commercial fertilizer and livestock feed. This led to increasing pollution of the aquatic environment with nutrients and at the beginning of the 1980s, episodes of extensive oxygen deficit started to occur in the open marine waters. To address this problem, political agreement was reached in 1985 on an action plan to reduce agricultural discharges of nitrogen, phosphorus and organic matter, the so-called NPo Action Plan. This prohibited direct discharges of manure and silage leachate, etc. from farms, prohibited the spreading of manure in the early autumn and on frozen soil, and imposed livestock density requirements.

Following the discovery of dead lobsters in the Kattegat off Gilleleje in autumn 1986, the politicians came under increasing pressure to take action. This resulted in adoption of the first Action Plan on the Aquatic Environment in 1987. The objective was to reduce combined nitrogen loading of the aquatic environment from agriculture, industry and wastewater treatment plants by 50% within a three-year period. Nitrogen losses from agricultural sources were to be reduced by 49% (*Table 3.8.1*). The measures directed at the agricultural sector were:

- Requirements as to manure storage capacity
- Requirements as to green cover during the autumn
- Obligatory crop rotation and fertilization plans.

The NPo Action Plan and the Action Plan on the Aquatic Environment were largely based on the concept that the agricultural sector should reduce pollution voluntarily and through good farming practice. Even though the sector largely complied with the requirements of the Action Plan in the Aquatic Environment by the end of the 1980s, this did not lead to marked improvement in fertilization practice towards improved utilization of manure nitrogen content in the early 1990s and hence to a consequent reduction in the consumption of commercial fertilizer.

Due to the lack of results, Parliament adopted the Action Plan for Sustainable Agriculture in 1991. The deadline for attainment of the target of reducing annual nitrogen leaching by 100,000 tonnes was extended to 2000, and the following additional requirements imposed:

- The majority of liquid manure had to be applied in the spring
- Obligatory crop rotation and fertilization plans and fertilization budgets based on specified nitrogen norms for the various crops
- Minimum requirements as to utilization of manure nitrogen content.

In 1996, Parliament further tightened the fertilization regulations.

In 1995, the annual reports of the Nationwide Monitoring Programme set up in connection with the Action Plan on the Aquatic Environment started to conclude that the target for reducing nitrogen leaching from arable land could not be attained solely by the measures stipulated in the plan. Severe oxygen deficit in Mariager Fjord in late autumn 1997 combined with criticism from the EU Commission in connection with implementation of the Nitrates Directive concerning Denmark’s lack of compliance with the national reduction target brought the action plans back onto the political agenda. Parliament thus ordered a scientific evaluation of the effectiveness of the regulatory instruments already implemented and of those planned. On the basis of this, Parliament adopted the follow-up plan – Action Plan on the Aquatic Environment II – in February 1998. The new plan focuses solely on nitrogen leaching from fields. The target stipulated in the preceding action plans is reiterated, and the measures to attain the target have to be implemented by 2003 at the latest. The Action Plan aims to meet the target through a broad range of measures encompassing various land use measures, improved utilization of livestock feed nitrogen content and further regulation of fertilizer use.

	1960	**1985**	**1987**	**1989**	**1991**	**1993**	**1996**	**1998**	**2000**	**2001**	**2003**
Strong growth in agricultural production with increasing import of commercial fertilizer and livestock feed	➔	➔									
Impact on the aquatic environment		↓↓									
NPo Action Plan		↑									
Action Plan on the Aquatic Environment (APAE)			↑								
Action Plan for sustainable Agriculture (APSA)					↑						
Follow-up on APSA							↑				
Action Plan on the Aquatic Environment II (APAE-II)								↑			
Midterm evaluation of APAE-II									↑		
Revision of measures in APAE-II										↑	
Full implementation of APAE-II by the end of 2003											↑

Figure 3.8.1
Chronology of the various action plans.

3.8.2 Objective of the two aquatic environment action plans

The first Action Plan on the Aquatic Environment from 1987 was based on calculations of the magnitude of the individual sources of nutrient loading given in the report of the NPo Action Plan. Total nitrogen loading of the aquatic environment from agricultural sources was calculated to be 260,000 tonnes per year (*Table 3.8.1*), consisting of a farmyard load (direct discharges from farms) and a field load (leaching from the root zone). The agricultural sector was required to reduce annual nitrogen losses by a total of 127,000 tonnes. This baseline figure of 260,000 tonnes was maintained in subsequent action plans.

The calculations for the subsequent Action Plan for Sustainable Agriculture presupposed that the farmyard load back in the mid 1980s was 30,000 tonnes N and the field load 230,000 tonnes N. The field load was required to be reduced by 100,000 tonnes N, while the remainder of the total reduction target of 130,000 tonnes N was to be attained through cessation of direct discharges (the farmyard load) in accordance with the NPo Action Plan and the Action Plan on the Aquatic Environment.

New calculations made in the 1990s indicate that the total nitrogen loss from agricultural sources in the mid 1980s had been underestimated. Thus in a report on the nitrogen surplus and losses in Danish agriculture, the total loss of nitrogen was estimated to be around 300,000 tonnes per year.

The revised calculations of the total nitrogen loss are based on different premises and are not immediately applicable in connection with the midterm evaluation of Action Plan on the Aquatic Environment II. If regulation of agricultural nitrogen losses to the aquatic environment is to be based on the revised figure for total loss, it will be necessary to re-evaluate the target and recalculate the effects of the measures implemented. The midterm evaluation of the Action Plan has therefore been undertaken solely on the basis of the original premises.

3.8.3 Evaluation of the effects of preceding action plans

The effects of the measures in Action Plan on the Aquatic Environment II depend on implementation of measures in the preceding action plans. It is therefore necessary to base the midterm evaluation on development in the agricultural sector during the preceding Action Plan on the Aquatic Environment and the Action Plan for Sustainable Agriculture.

Table 3.8.1
Action Plan on the Aquatic Environment (APAE) reduction targets for nitrogen (N) losses from agricultural sources.

	Discharge according to NPo report (tonnes N)	Reduction target (tonnes N)	%	Discharge after implementation of APAE (tonnes N)
Agriculture	260,000	127,000	49	133,000
Municipal WWTPs	25,000 *	15,000	60	10,000
Separate industrial discharges	5,000	3,000	60	2,000
Total	**290,000**	**145,000**	**50**	**145,000**

* Discharge of nitrogen from wastewater treatment plants was overestimated in 1984 (best estimate 20,000).

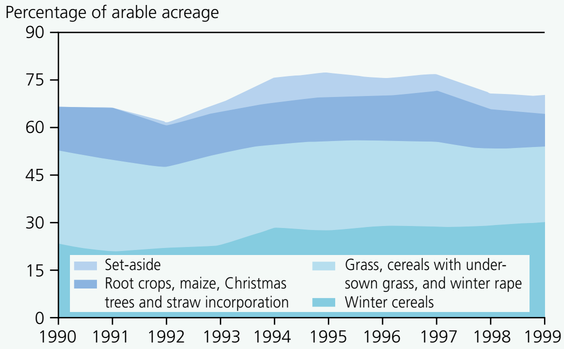


Figure 3.8.2
Trend in the percentage of arable acreage with green cover during the period 1990–99. (Source: Grant et al., 2000b).

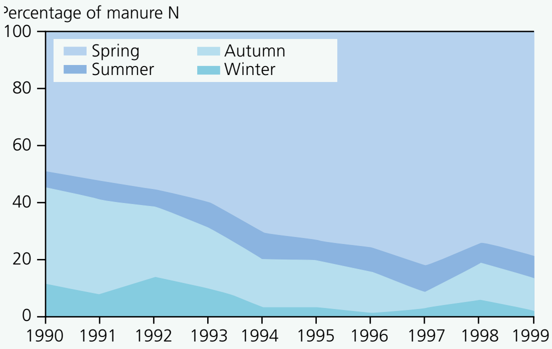


Figure 3.8.3
Trend in percentage of manure nitrogen spread in the spring (March–May), summer (June–August), autumn (September–November) and winter (December–February) during the period 1990–99. (Source: Grant et al., 2000b).

Green cover

One of the requirements of the Action Plan on the Aquatic Environment was for 65% green cover on fields in the autumn. The intention was that the vegetation should take up the nitrogen remaining in the soil after the year's harvest and retain the nitrogen for the following year's crop.

The requirement for 65% green cover on fields was fulfilled during the whole period 1990 to 1999. Of the total green cover, approx. 36% was accounted for by grass, cereals undersown with grass, and winter rape, approx. 40% by winter cereals, approx. 16% by root crops, maize, Christmas trees and straw incorporation, and approx. 8% by set-aside (*Figure 3.8.2*).

Only fields with grass, cereals undersown with grass, and winter rape, i.e. just over a third of the acreage with green cover, take up significant amounts of nitrogen in the autumn and winter months. Recent studies show that winter wheat is of limited value as a means of taking up nitrogen in the autumn. The actual value of the measures has therefore been less than originally expected.

Utilization of manure nitrogen content

Both the Action Plan on the Aquatic Environment and the Action Plan for Sustainable Agriculture included measures aimed at improving utilization of manure nutrient content.

- The Action Plan on the Aquatic Environment required farmers to have a minimum of 9 months storage capacity for the liquid manure produced on their farms. This was revised in the Action Plan for Sustainable Agriculture to a requirement that there had to be sufficient storage capacity to enable compliance with the regulations on manure spreading times. This normally corresponds to nine months storage capacity on pig holdings, and seven months on cattle holdings in which the animals are put out to graze in the summer. All farms are required to have a minimum of six months storage capacity, though.
- The Action Plan for Sustainable Agriculture prohibits the spreading of manure between harvest and 1 February.
- The Action Plan for Sustainable Agriculture also contains requirements as to minimum permissible utilization of manure nitrogen content.

Considerable expansion of slurry storage facilities took place during the 1990s, thereby increasing total manure storage capacity. At the beginning of the 1990s, only about 40% of the manure could be stored for at least nine months, while the proportion had increased to approx. 85% in 1999.

As a result of the improved storage capacity, the time of year the manure is spread has also changed markedly during the same period. Thus the proportion of manure spread in spring and summer has increased from 55% in 1990 to 86% in 1999 (*Figure 3.8.3*). By spreading the manure in the spring and summer instead of in the autumn it is spread at a time when the crops can take up the nutrients it contains. This reduces the risk of leaching, and the nutrients in the manure can replace commercial fertilizer, thereby reducing consumption of the latter.

At the beginning of the 1990s, virtually all manure was applied by overall spreading. In 1999 the figure had fallen to 49%, with 51% being spread with trailing hoses or by direct incorporation (*Figure 3.8.4*).

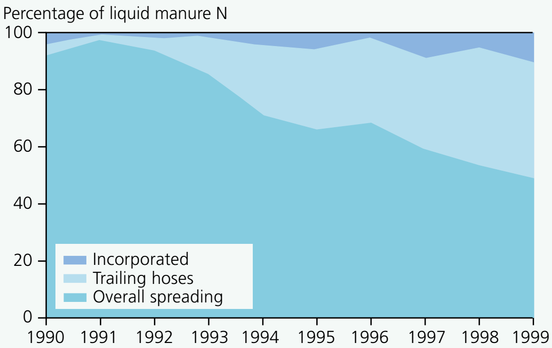


Figure 3.8.4

Trend in spreading methods for liquid manure during the period 1990–99.

(Source: Grant et al., 2000a).

Photo: DFNA/Bent Lauge Madsen

Ammonia volatilization from the manure is considerably reduced when it is spread using trailing hoses, and even more so when the manure is directly incorporated into the soil. When ammonia volatilization is reduced, more nitrogen is available to be taken up by the crops, thereby enabling the consumption of commercial fertilizer to be reduced.

As a result of the above-mentioned measures, the nitrogen content of manure is now utilized more optimally. The proportion of the nitrogen in the manure that can be taken up by the crops (the effective part) has thus increased from approx. 34% in 1990 to 46% in 1998 and 45% in 1999.

Legally binding fertilization norms

One of the measures in the Action Plan for Sustainable Agriculture was a requirement that farmers should prepare crop rotation and fertilization plans as well as fertilization budgets based on specified nitrogen norms for the individual crops. The norms are set annually by the Danish Plant Directorate and reflect the economically optimal nitrogen needs of the crop. The crop nitrogen norms are used to determine the maximum fertilizer quota for the individual holdings. Each year, the holdings have to submit fertlization budgets to the Danish Plant Directorate to account for the quota, fertilizer consumption and utilization of manure. Regulation and control is solely carried out at the holding level. The aim of the fertilization norms is to ensure that crops are not overfertilized relative to their needs, and that the nitrogen content of manure is used appropriately.

The difference between the effective amount of nitrogen applied (commercial fertilizer plus that part of manure nutrient content that the crops can utilize) and the nitrogen quota corresponds to overfertilization. Overfertilization decreased during the 1990s and was zero in 1998 and 1999 (*Figure 3.8.5*).

The measures contained in the first action plans have all contributed to a reduction in consumption of commercial fertilizer. The 4.1% reduction in cultivated acreage, the other changes in land use and improved fertilization practice have also contributed to the reduction in consumption of commercial fertilizer, which decreased from just under 400,000 tonnes N per year in the late 1980s to 257,000 tonnes N in 1999, a reduction of 34% (*Figure 3.8.5*).

The midterm evaluation of Action Plan on the Aquatic Environment II calculated that annual nitrogen leaching has decreased by 66,000 tonnes during the same period, of which approx. 12,000 tonnes were accounted for by changes in the use of cultivated land, approx. 4,000 tonnes by improved utilization of the nitrogen content of livestock feed, and approx. 50,000 tonnes by changes in fertilization practice, including the effects of the first action plans.

The calculated reduction in annual nitrogen leaching is 3,000 tonnes greater than originally expected when the Action Plan was adopted. This is due to the fact that land was set aside in 1997 and 1998 that had been expected to be used for agricultural production when the Action Plan was adopted.

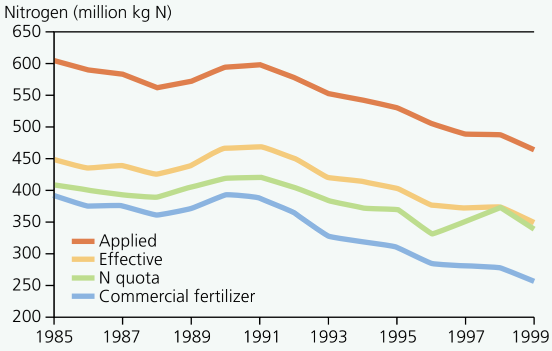


Figure 3.8.5

Trends in consumption of commercial fertilizer nitrogen, total nitrogen applied, bioavailable (effective) nitrogen and the nitrogen quota for the country as a whole for the period 1985–99. The nitrogen quota is calculated from the crops actually cultivated and their economically optimal nitrogen requirement.
(Source: Grant et al., 2000a).

Measure	**Reduction in nitrogen leaching (tonnes N per year)**
Reduction in cultivated land	8,000
Set-aside	3,800
Organic farming	500
Modified feeding practice	4,000
Other changes in farming practice	49,700
Changes in agriculture, total	**66,000**

Table 3.8.2

Calculated reduction in nitrogen leaching achieved with various measures under the Action Plan on the Aquatic Environment and the Action Plan for Sustainable Agriculture during the period 1989/90–97/98.
(Source: Grant et al., 2000a).

3.8.4 Evaluation of the effects of Action Plan on the Aquatic Environment II

The following section assesses the effects of the measures contained in Action Plan on the Aquatic Environment II up to 1999, and gives a projection of the effects up to 2003. The measures can be subdivided into three groups:

- Land use measures
- Livestock feed measures
- Fertilization measures.

The first two groups are based on expectations as to development within the agricultural sector while the third group comprises actual requirements to the sector.

Land use measures

Under the Action Plan, nitrogen leaching was to be reduced through the re-establishment of wetlands, afforestation, environment-friendly agricultural practices and conversion to organic farming. When the Action Plan was adopted, the amount of land expected to be converted to the various measures by 2003 was estimated and the effect on nitrogen leaching thereafter calculated.

Wetlands, e.g. flooded or inundated meadows, will remove nitrogen from the water flowing through them and thereby reduce the amount of nitrogen reaching the watercourses and coastal waters. The Action Plan presupposed that 16,000 ha would be re-established during the period 1998 to 2003, thereby removing 5,600 tonnes N per year. At the end of 2000, only 87 ha had been re-established and funds had been granted for the re-establishment of a further 1,078 ha. It has proven very difficult to establish the necessary agreements with landowners, among other reasons because of the increasing price of arable land. Moreover, the whole process involving pilot studies and drawing up agreements with landowners has taken considerably longer than expected.

The Danish Forest and Nature Agency and the Counties have therefore reduced the expected area to 5,000–7,000 ha of wetlands by 2003 (*Table 3.8.3*). As a consequence, the expected nitrogen removal in wetlands will amount to 2,100 tonnes per year. In addition, consumption of commercial fertilizer nitrogen will be reduced by 400 tonnes as the land converted to wetlands will no longer need to be fertilized.

Less nitrogen usually leaches from forest than from arable land. Increasing the area of forest will therefore reduce leaching. The Danish Parliament decided as early as 1989 that the area of forest was to be doubled over the following 80–100 years, corresponding to afforestation of 5,000 ha per year.

In the mid 1990, annual afforestation amounted to approx. 1,800 ha. The Action Plan encompassed a support scheme that has promoted private afforestation such that afforestation in 1998 and 1999 amounted to a total of 6,500 ha (*Figure 3.8.6*).

When the Action Plan was adopted it was expected that 20,000 ha of new forest would be established

Status at end of 2000:	**(ha)**
Re-established	87
Funding granted for implementation	1,078
Funding granted for pilot projects	6,371
Estimate 2003:	**(ha)**
Resived target	6,000

Table 3.8.3

Status and estimate for wetland re-establishment at the midterm evaluation of Action Plan on the Aquatic Environment II (estimate by the Danish Forest and Nature Agency and the Counties).

(Source: Grant et al., 2000a).

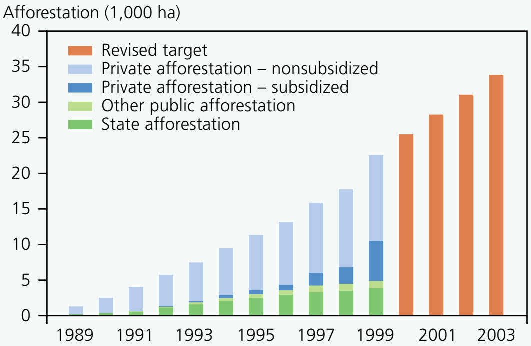


Figure 3.8.6

Trend in afforestation acreage from 1989 to 1999 together with projection up to 2003 (estimate by the Danish Forest and Nature Agency).

(Source: Grant et al., 2000a).

during the period 1998–2003, thereby reducing annual nitrogen leaching by 1,100 tonnes. At the midterm evaluation the projection for total afforestation has been reduced to 17,340 ha. It is thus expected that annual consumption of commercial fertilizer nitrogen will be reduced by 2,400 tonnes, while annual nitrogen leaching will be reduced by 900 tonnes.

Since 1993, it has been possible to obtain financial support for agri-environmental measures. Within environmental sensitive areas (ESAs) designated by the Counties, farmers can enter into voluntary agreements to convert to various environment-friendly agricultural practices. Agreements on reduced nitrogen fertilization, set-aside, undersowing cereals with rye grass and changed drainage will all reduce nitrogen leaching. In 1996, approx. 65,000 ha were encompassed by agri-environmental measures, of which only approx. 13% can be expected to reduce nitrogen leaching.

The Action Plan presumed that an additional 88,000 ha would be converted to agri-environmental measures during the period 1997–2003, thus bringing the total area encompassed by such measures to approx. 153,000 ha in 2003. This was expected to reduce annual nitrogen leaching by 1,900 tonnes. During the period 1997–2000, agri-environmental measure agreements were entered into for approx. 35,000 ha, while 5-year agreements on approx. 27,000 ha expired. The additional area encompassed by such agreements was thus over 7,000 ha. The total area expected to be encompassed by agri-environmental measures in 2003 has therefore been reduced to 100,000 ha, corresponding to an additional 35,000 ha during the period of the Action Plan (*Figure 3.8.7*).

Assuming that the relative distribution of acreage between the different types of agri-environmental measure continues as for the period 1997–2000, approx. 25,000 ha will have an effect on nitrogen leaching. It is expected that annual consumption of commercial fertilizer N will thereby be reduced by 2,800 tonnes, and annual nitrogen leaching by 900 tonnes.

The magnitude of leaching from organically farmed land is not known, but the difference in nitrogen balances for organically farmed and conventionally farmed fields indicates that less nitrogen leaches from organically farmed fields. The difference between the two farming practices is diminishing, however, as fertilization restrictions are increasingly being imposed on conventional farming. The midterm evaluation presupposes that nitrogen leaching from organically farmed fields is approximately 10 kg per ha lower than from conventionally farmed fields.

In 1997, total organically farmed acreage (converted or under conversion) amounted to 64,300 ha, corresponding to 4.2% of all cultivated land. The Action Plan presupposed that organically farmed acreage will increase by 170,000 ha during the period 1998–2003, thereby bringing the total to 234,000 ha in 2003. This was expected to reduce annual nitrogen leaching by 1,700 tonnes.

In 1998–1999, 82,400 ha were converted to or were under conversion to organic farming. The degree of conversion was particularly high in 1999 due to the expectation that less favourable subsidy regulations would be introduced.

Under the midterm evaluation, the Danish Institute for Agricultural and Fisheries Economics has reduced the acreage expected to be farmed organically in 2003 to 220,000 ha. This corresponds to an additional 155,700 ha during the period of the Action Plan (*Figure 3.8.8*). It is estimated that this will reduce

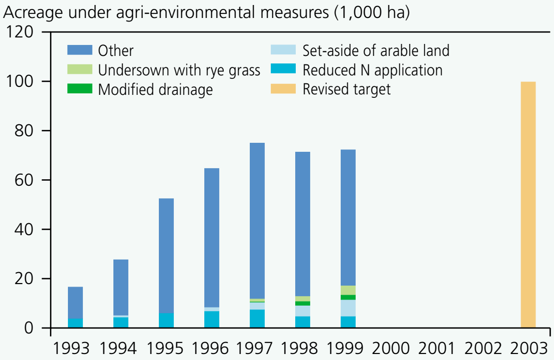


Figure 3.8.7

Trend in acreage with agri-environmental measure agreements from initiation of the scheme in 1993 to 1999 together with projection up to 2003 (the target is set by the Ministry of Foods, Agriculture and Fisheries). (Source: Grant et al., 2000a).

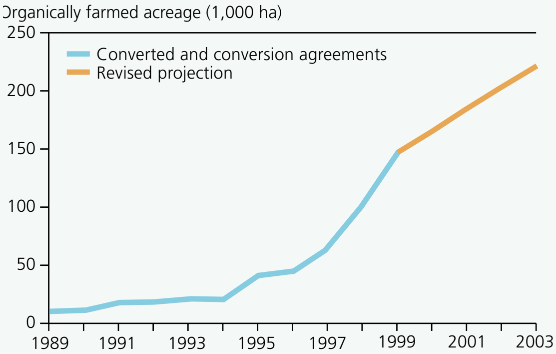


Figure 3.8.8

Trend in organically farmed acreage for the period 1989–99 together with projection up to 2003 (estimate by the Danish Institute of Agricultural and Fisheries Economics). (Source: Grant et al., 2000a).

annual consumption of commercial nitrogen fertilizer by 2,400 tonnes and annual nitrogen leaching by 1,600 tonnes.

The Action Plan was generally too optimistic with regard to conversion of land to uses that would reduce nitrogen leaching, especially as regards wetlands and ESAs (*Table 3.8.4*). At the midterm evaluation, expectations as to the environmental effect of the land use measures have been roughly halved. Annual consumption of commercial nitrogen fertilizer is now expected to be reduced by 16,600 tonnes as compared with the original estimate of 31,000 tonnes, and annual leaching of nitrogen is expected to be reduced by 5,500 tonnes as compared with the original estimate of 10,300 tonnes.

Livestock feed measures

Efforts are being made through research and farmer advisory services to improve utilization of livestock feed nitrogen content so as to reduce the amount of nitrogen excreted in manure.

The original expectation was that improved utilization of feed nitrogen content would reduce annual nitrogen excretion in manure by approx. 26,000 tonnes in 2003, and thereby reduce annual nitrogen leaching by 2,600 tonnes.

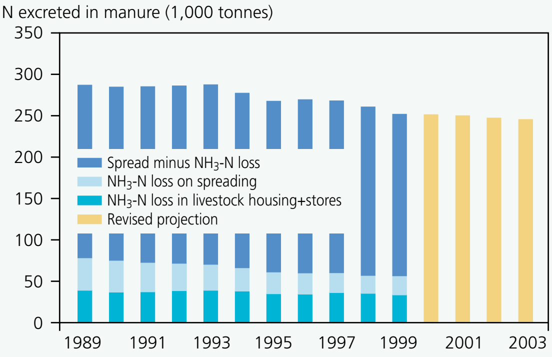


Figure 3.8.9

Annual amount of nitrogen excreted in manure (ex animal) together with projection up to 2003. During the duration of Action Plan on the Aquatic Environment II (1998–2003), N excretion is shown assuming unchanged livestock production, and the changes are therefore solely attributable to the effect of improved feed utilization. (Source: Grant et al., 2000a).

During the period from 1997 to the end of 1999, annual nitrogen excretion in manure decreased by 15,000 tonnes. At the midterm evaluation a further decrease of 7,000 tonnes is expected by 2003 assuming unchanged production of meat and milk. The nitrogen content of manure is thus expected to decrease by 8% during the period of the Action Plan (*Figure 3.8.9*).

Table 3.8.4

Overview of implementation and targets for land use measures under Action Plan on the Aquatic Environment II.

	Reduction of nitrogen leaching	**Area and nitrogen reduction targets 1998–2003**	**Status at midterm evaluation and revised target for 1998–2003**
Re-establishment of wetlands	Wetlands, e.g. flooded or wet meadows, will remove nitrogen from the water that flows through them, and hence reduce nitrogen loss to watercourses and coastal waters	Re-establishment of 16,000 ha of wetlands, thus removing 5,600 tonnes N	87 ha re-established by the end of 2000. Funds granted for re-establishment of 1,078 ha. Revised target for 2003: 5,000–7,000 ha of wetlands, thus removing 2,100 tonnes N
Afforestation	Less nitrogen generally leaches from forest than from arable land, and afforestation therefore reduces nitrogen loss	Afforestation of 20,000 ha, thus reducing leaching by 1,100 tonnes N	6,500 ha afforested in 1998 and 1999. Revised target for 2003: Afforestation of 17,340 ha, thus reducing leaching by 900 tonnes N
Environmentally sensitive areas (ESAs)	Agreements on agri-environmental measures within the designated ESAs, e.g. reduced nitrogen fertilization or extensive land management will reduce nitrogen loss	Agri-environmental measure agreements on an additional 88,000 ha, thus reducing leaching by 1,900 tonnes N	7,000 ha additional agreements in 1997–1999. Revised target for 2003: 35,000 ha additional agreements, thus reducing leaching by 900 tonnes N
Organic farming	Commercial fertilizer is not used in organic farming, the nutrient supply instead being maintained through crop rotation. This generally reduces nitrogen loss	Conversion of 170,000 ha, thus reducing leaching by 1,700 tonnes N	82,400 ha converted in 1998 and 1999. Revised target for 2003: Conversion of 156,000 ha, thus reducing leaching by 1,600 tonnes N

It is especially the reduction in the organically bound nitrogen fraction in manure that is expected to reduce nitrogen leaching. In contrast, a reduction in the ammonia content of manure will probably be compensated for by a corresponding increase in consumption of commercial fertilizer. It is estimated that for each kilogram reduction in the organic nitrogen content of manure, leaching will decrease by 0.3–0.4 kg, corresponding to a reduction in annual nitrogen leaching of approx. 3,100 tonnes by the end of 2003. This is the only measure that the midterm evaluation considers will have a greater effect than that presupposed in the Action Plan. The resultant increase in annual consumption of commercial fertilizer nitrogen is estimated to be around 10,000 tonnes.

Fertilization measures

These measures encompass tightened livestock density requirements, a requirement for catch crops on an additional 6% of farm base area, reduced crop nitrogen norms and more stringent requirements on utilization of manure nitrogen content. All the measures affect fertilization practice, and it is not possible to identify the effects of the individual measures. The first three measures were legally implemented in the fertilization year 1998/99, while the more stringent requirements on utilization of manure nitrogen content were introduced stepwise in the fertilization years 1999/2000 to 2002/2003.

The livestock density requirement specifies the upper limit for the total amount of manure that may be spread on a farm (kg N per ha). The livestock density requirement was tightened in connection with implementation of the Nitrates Directive, and is also included as one of the measures under the Action Plan. For cattle holdings, the more stringent regulations mean that the manure has to be spread on a larger area, while the pig holdings are only very slightly affected (*Figure 3.8.10*). The environmental effect of tightening the regulations will be very limited. It will only reduce total nitrogen leaching in cases where it leads to a reduction in livestock production.

Another measure under the Action Plan is a requirement that catch crops are established on a further 6% of the land that does not already have autumn green cover (beet, maize, grass or winter catch crops). This is called the "6% catch crop" rule. The intention is that the autumn catch crops will take up the nitrogen remaining in the soil after the year's harvest. Measurements and experimental data show that nitrogen leaching can be reduced by an average of 25 kg N per ha if the catch crop is not fertilized. The nitrogen taken up in the catch crop serves as a nitrogen reserve for the subsequent crops, thus enabling consumption of commercial fertilizer nitrogen to be reduced correspondingly in the long term.

The Action Plan presupposes that this requirement will entail the establishment of an additional 120,000 ha of catch crops, and that annual nitrogen leaching will thereby be reduced by 3,000 tonnes. Data from fertilization accounts notified to the Danish Plant Directorate by the agricultural sector in 1999 show that the additional 6% required acreage of catch crops was approx. 240,000 ha. It is not yet possible to predict whether the additional area of catch crops will continue to be greater than presupposed in the Action Plan in the future since the requirement can be complied with as an average over four years. The legislation permits the catch crops to be fertilized if they are to be harvested. This conflicts with the intention of the measure, which therefore cannot be expected to have the presupposed effect on nitrogen leaching.

The Action Plan reduces crop nitrogen norms by 10% of the economically optimal norms for the fertiliza-

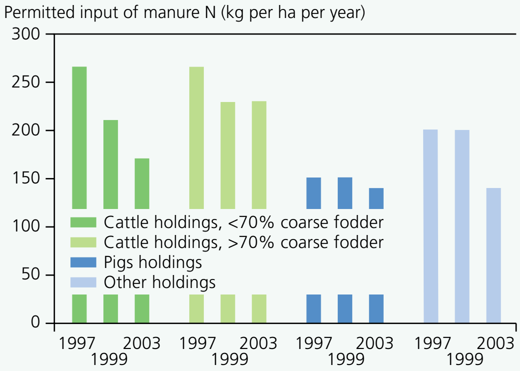


Figure 3.8.10

Effect of tightening of livestock density requirements in 1999 and 2003 on total amount of manure N that may be spread annually on a holding.

(Source: Grant et al., 2000a).

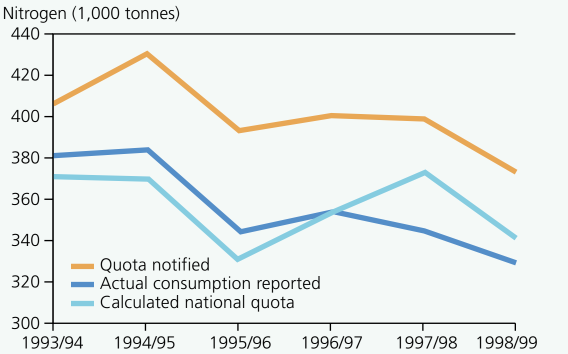


Figure 3.8.11

Calculated national nitrogen quota, nitrogen quota notified by the agricultural sector and actual consumption of nitrogen fertilizer reported by the agricultural sector for the period 1994/95–98/99.

(Source: Grant et al., 2000b).

tion year 1998/99 onwards. The reduction in the nitrogen norms is expected to reduce the national annual nitrogen quota by 40,000 tonnes and yield a corresponding reduction in consumption of commercial fertilizer nitrogen.

Based on data for fertilizer consumption and fertilization practice in 1998/99 – the first year under the Action Plan – it is estimated that the tightened livestock density requirements, 6% additional catch crops and reduced crop nitrogen norms have reduced annual consumption of commercial fertilizer nitrogen by approx. 22,800 tonnes. The calculation takes into account the changes in commercial fertilizer consumption resulting from the land use measures and other changes in the use of cultivated land.

That the effect of the fertilization measures is not fully manifested is due to the fact that when the fertilization norms are applied in practice, there is room for the agricultural sector to apply approx. 30,000 tonnes of nitrogen per year more than presupposed in the Action Plan. In other words, the farmers' fertilization accounts leave room to manoeuvre (*Figure 3.8.11*). As a consequence, the reduction in fertilization norms will not necessarily entail a corresponding reduction in consumption of commercial fertilizer. The main reasons for this "room to manoeuvre" are the possibility to fertilize catch crops and the possibility to use a higher fertilization norm for grass than originally presupposed. It can be expected that consumption of commercial fertilizer will decrease as expected if the regulations and administrative practice are tightened such that the agricultural sector's quota lies closer to the expected level.

The Action Plan presupposes that annual nitrogen leaching will be reduced by 10,600 tonnes by improved utilization of manure nitrogen content. The utilization of manure nitrogen content is to be raised by 5 percentage points in the fertilization year 1999/2000 and a further 5 percentage points in 2001/2002.

Moreover, the Action Plan stipulates that if the midterm evaluation showed that the target could not be reached through straw incorporation, permanent set-aside and organic farming, etc., the utilization percentage was to be increased further in 2002/2003 to whatever extent was technically feasible in order to ensure that annual nitrogen leaching was reduced by 10,600 tonnes. As the reduction in nitrogen leaching achieved with the other Action Plan measures at the midterm evaluation fell short of the targets, it was decided to raise the utilization of manure nitrogen content by 15 percentage points. As this more stringent requirement for utilization of manure nitrogen content had not entered into force at the midterm evaluation, the assessment pertains solely to the expected effect.

The calculations presuppose that the increased utilization will be fully reflected as a reduction in consumption of commercial fertilizer nitrogen. The expected reduction in annual nitrogen leaching is now approx. 7,600 tonnes, i.e. 3,000 tonnes less than originally presupposed in the Action Plan. The reason for the reassessment is two clear developments in agriculture, namely that less manure is being produced than presupposed at the time the Action Plan was formulated, and that the spring application of manure has ceased (*Figure 3.8.3*).

Table 3.8.5
Midterm evaluation forecasts of the effect of Action Plan on the Aquatic Environment II (APAE-II) on nitrogen leaching and consumption of commercial fertilizer together with the original APAE-II targets. (Source: Grant et al., 2000a).

	Reduction in leaching in 2003 (tonnes N)		**Reduction in commercial fertilizer consumption in 2003 (tonnes N)**	
	Forecast Midterm evaluation	**APAE-II target**	**Forecast Midterm evaluation**	**APAE-II target**
Land use measures	5,500	10,300	16,600	31,000
Improved feed N utilization	3,100	2,400	-10,000	-13,600
Fertilization measures	15,800	24,400	53,300	72,000
Total	**24,400**	**37,100**	**59,800**	**87,100**

Environmental impact of Action Plan on the Aquatic Environment II

Overall, the measures encompassed by the Action Plan are expected to reduce annual nitrogen leaching by 24,400 tonnes as compared with the original expectation of 37,100 tonnes. Similarly, annual consumption of commercial fertilizer nitrogen is expected to fall by 59,800 tonnes as compared with the original expectation of 87,100 tonnes (*Table 3.8.5*).

3.8.5 Effect of the expected development in the agricultural sector

Evaluation of the effect of the Action Plan is based on land use and livestock production in 1997/98. A projection of the general development in Danish agriculture made by the Danish Institute of Agricultural and Fisheries Economics taking into account EU Common Agricultural Policy and the Agenda 2000 reform indicates that the following developments will take place up to 2003:

- A shift from winter cereals to spring cereals and a decrease in acreage of grass and fodder beet, and of pulses. The changed crop mix is expected to result in an increase in the national nitrogen quota.
- An increase in set-aside acreage and a decrease in cultivated acreage. This is expected to result in a decrease in the nitrogen quota.
- As a result of the decrease in the area of cultivated land requiring nitrogen, the reduction in the nitrogen norm (10% less than the economically optimal level) will have less effect compared with the land use in 1998.
- A reduction in the dairy herd that will probably be counterbalanced by an increase in yield such that milk production remains unchanged. The effect of these changes is incorporated in the improved utilization of feed nitrogen content.
- The production of slaughter pigs will increase from 21 million pigs as presupposed in the Action Plan calculations to approx. 23.6 million pigs in 2003. This increase is expected to increase annual nitrogen leaching by around 1,500 tonnes and to reduce annual consumption of commercial fertilizer nitrogen by 5,100 tonnes (*Table 3.8.6*).

Overall, it is estimated that the expected changes in land use will reduce annual consumption of commercial fertilizer nitrogen by 8,400 tonnes and reduce annual nitrogen leaching by 3,550 tonnes (*Table 3.8.6*). Together, the changes in agricultural production up to 2003 will therefore reduce annual consumption of commercial fertilizer nitrogen by 13,500 tonnes and reduce annual nitrogen leaching by 2,050 tonnes.

Photo: DFNA/Bent Lauge Madsen

Table 3.8.6

Effect on consumption of commercial fertilizer and nitrogen leaching of the expected development in agriculture taking into account EU agricultural policy for the period 1998–2003. (Source: Danish Institute of Agricultural and Fisheries Economics, 2000).

	Reduction in commercial fertilizer consumption (tonnes N)	Reduction in leaching (tonnes N)
Crop mix	-3,000	-750
Changes in cultivated and set-aside acreage	11,400	4,300
Increase in pig production	5,100	-1,500
Total	**13,500**	**2,050**

3.8.6 Prognosis for attainment of the target in 2003

Development in the agricultural sector is a complicated interplay controlled primarily by market economics and agricultural regulations. The prognosis as to attainment of the target stipulated in the two aquatic environment action plans therefore has to be seen in relation to this. Overall, the various measures are together estimated to reduce annual nitrogen leaching by 92,600 tonnes in 2003. This is just over 7,000 tonnes short of the target reduction in annual nitrogen leaching of 100,000 tonnes (*Table 3.8.7*).

Annual consumption of commercial fertilizer nitrogen has fallen from 400,000 tonnes in the mid 1980s to 277,000 tonnes in 1997/1998. It is expected that annual consumption will be reduced by a further 73,000 tonnes up to 2003 (*Table 3.8.7*) such that annual consumption of commercial fertilizer nitrogen will be around 204,000 tonnes in 2003. If the target of a 100,000 tonne reduction in annual nitrogen leaching is to be achieved, annual consumption of commercial fertilizer nitrogen will have to be reduced by a further 20,000–25,000 tonnes.

Photo: C Danmark

	Reduction in leaching in 2003 (tonnes N)		**Reduction in commercial fertilizer consumption in 2003 (tonnes N)**	
Measures	**Forecast Midterm evaluation**	**APAE-II target**	**Forecast Midterm evaluation**	**APAE-II target**
Preconditions for APAE-II:				
Effect attained with APAE-I and Action Plan for Sustainable Agriculture	66,000 **	ca. 63,000 *	123,000	123,000
State- and county-financed restoration projects	200	0		
APAE-II				
• **Wetlands**	2,100	5,600	400	1,100
• **Afforestation**	900	1,100	2,400	2,440
• **Environmentally Sensitive Areas**	900	1,900	2,800	10,000
• **Organic farming**	1,600	1,700	10,900	17,600
• **Improved utilization of feed N**	3,100	2,400	-10,000	-13,600
• **Livestock density requirements**		300	22,800	600
• **Catch crops**		3,000		
• **Reduced N norm**	15,800	10,500		40,000
• **Improved utilization of manure N**		10,600	30,500	26,000
APAE-II, total	**24,400**	**37,100**	**59,800**	**87,140**
General trend and Agenda 2000, 1998–2003	2,000		13,500	
Total reduction	**92,600**	**100,000**	**196,300**	**210,140**

* Based on 1995/96 data projected to 1997

** Reassessed during the midterm evaluation on the basis of 1997/98 data

Table 3.8.7
Midterm evaluation forecast of the effect of Action Plan on the Aquatic Environment II (APAE-II) on nitrogen leaching and consumption of commercial fertilizer when all the measures are implemented by 2003 together with the original APAE-II targets. (Source: Grant et al., 2000a).

3.8.7 Effects on the aquatic environment

During the period 1989 to 1999, nitrogen leaching from agricultural land accounted for around 80% of total nitrogen input to Danish watercourses. The amount of nitrogen leached from the root zone and hence the input to the watercourses varies from year to year, primarily due to variation in annual precipitation and hence in water transport and nitrogen leaching from arable land.

When the water has left the root zone of the fields, part of it will flow via surface runoff and rapidly reach the watercourses, and part will percolate down to the groundwater before eventually reaching the watercourses. During transport in the soil and groundwater the nitrogen content of the water is reduced, among other means through biological denitrification and chemical reduction processes (*Figure 3.8.12*). Thus only about 30–40% of the nitrogen leaving the root zone of fields reaches the watercourses.

The reduction target given in the Action Plan pertains to the leaching of nitrogen from arable land to the aquatic environment. The two aquatic environment action plans do not stipulate quality objectives for the aquatic environment, although the focus of attention is naturally on detectable effects in the watercourses, lakes and fjords. It is estimated that annual nitrogen leaching had been reduced by 66,000 tonnes in 1998/1999, corresponding to a 29% reduction relative to the situation prior to the first Action Plan on the Aquatic Environment. Measurements of nitrogen leaching from the root zone of arable land have shown that this had decreased significantly by the same order of magnitude (*Figure 3.8.12*).

A decrease in nitrogen transport has also been recorded in watercourses. However, the decrease is less than in the root zone and is highly dependent on the transport pathways and processes in the hydrological cycle. In clayey soil areas, a large part of the percolating water flows to watercourses via subsurface flow,

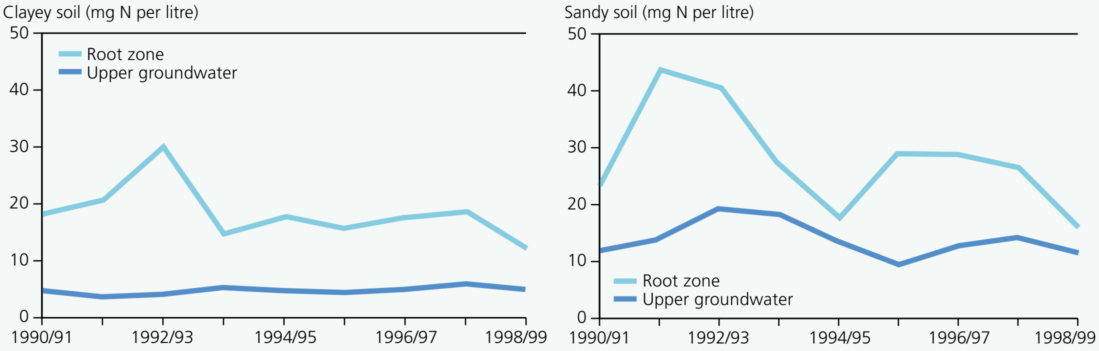


Figure 3.8.12

Trend in flow-weighted nitrogen concentrations in water leaving the root zone of the fields (approx. 1 m b.g.s.) and in the upper groundwater collected between 1.5 and 5 m b.g.s. in three clayey soil and 2 sandy soil agricultural monitoring catchments for the period 1990/91–98/99.

(Source: Grant et al., 2000b).

including drainage. As this flow is rapid, an effect of reduced nitrogen leaching from the root zone will therefore be detectable within a few years in clayey soil areas. An analysis of climate-corrected transport of nitrogen in watercourses draining clayey soil areas reveals a reduction of approx. 16% (*Figure 3.8.13*).

In sandy soil areas, flow to watercourses largely takes place via groundwater. During transport to and from the groundwater the nitrogen content of the water will be reduced. Thus it will take 10–20 years before an effect of reduced nitrogen leaching in sandy soil areas can be reliably measured. An analysis of the climate-corrected transport of nitrogen in sandy soil areas reveals a reduction of approx. 3% (*Figure 3.8.13*).

Due to time delays and reduction processes in the soil and groundwater, it will take a long time before the effect of the measures in the two aquatic environment action plans are fully reflected in the surface waters. It took approx. 25 years to build up the situation we faced in the 1980s, and we must expect that it will take just as long to reverse the situation.

The goal of the two aquatic environment action plans of halving nitrogen leaching from the root zone will not halve the nitrogen content of the surface waters. The natural background loading from both arable land and uncultivated countryside will continue. In many places, moreover, the leached nitrate is removed by denitrification in the groundwater and wetlands before it reaches watercourses. In these places a reduction in nitrate leaching will not lower the nitrate content of the outflowing water if it is already nitrate-free.

Halving nitrogen leaching from arable land is therefore hardly likely to reduce the nitrogen content of the surface water by more than 25–35%. The forthcoming implementation of the Water Framework Directive will focus attention on the environmental state of defined water bodies, as well as on the reductions needed to attain the desired state.

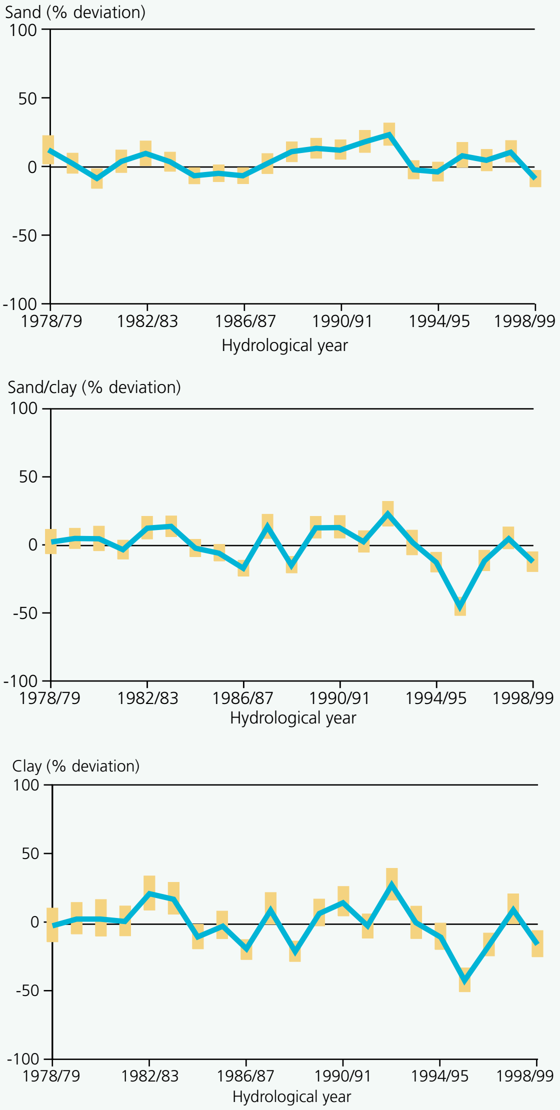


Figure 3.8.13

Climate (runoff)-corrected transport of nitrate-N in 55 watercourses in predominantly agricultural catchments. The catchments are subdivided into sandy soil, mixed sandy/clayey soil and clayey soil. For each soil type the horizontal line indicates the reference level (zero level) representing the average for the nine-year period preceding adoption of the Action Plan on the Aquatic Environment in 1987, i.e. 1978/79–1986/87. For each hydrological year the figure shows the corrected relative transport of nitrate-N for the watercourse group analysed indicating the deviation (±2 SD).

(Source: Bøgestrand, 2000).

3.8.8 Political follow-up on the midterm evaluation of Action Plan on the Aquatic Environment II

The political parties behind Action Plan on the Aquatic Environment II examined the midterm evaluation and had it explained in greater detail at a number of meetings in spring 2001. On 26 April 2001, agreement was reached to adjust the existing measures in the Action Plan as described below.

In order to considerably speed up the re-establishment of wetlands, the regulations will be amended to enable deviation from the former maximum subsidy following a specific evaluation, as well as to enable changes in former practice regarding land redistribution, relevant agri-environmental measures, etc. It is estimated that this will reduce annual nitrogen leaching by 1,500 tonnes within the agreed budget for wetlands.

With regard to catch crops on 6% of farm base area, the possibility to assign a nitrogen norm will be rescinded, and the residual nitrogen from the 6% catch crops will have to be included in the individual farm's nitrogen quota. It is estimated that this will reduce annual nitrogen leaching by 1,500 tonnes.

The nitrogen norm for bread wheat is currently higher than that for wheat cultivated for livestock feed. The number of hectares eligible for the bread wheat nitrogen supplement will be reduced from 330,000 ha to 50,000 ha. A maximum area of 50,000 ha is to be achieved by making it obligatory to document that wheat for bread manufacture has previously been cultivated and sold by the individual farm. It is estimated that this will reduce annual nitrogen leaching by 2,000 tonnes.

The nitrogen norms will be adjusted for a number of crops such as winter wheat, winter barley, permanent grass, set-aside, undersown grass and grass for cutting. This will bring the calculations of nitrogen quotas at farm level into better agreement with the intention behind the nitrogen norms. It is estimated that this will reduce annual nitrogen leaching by 2,325 tonnes.

The requirement for utilization of manure nitrogen content will be tightened by a further 5 percentage points as stipulated in the Action Plan. The effect of this is already included in the midterm evaluation.

Together with the effects of increased afforestation and improved practice with regard to the agri-environmental measures, these adjustments are expected to reduce the annual nitrogen leaching by a total of 7,575 tonnes. It is considered that this will enable the Action Plan target of a 100,000 tonne reduction in annual nitrogen leaching to be attained by 2003 (*Table 3.8.8*).

Table 3.8.8 Midterm evaluation forecast of the reduction in nitrogen leaching up to 2003 together with the expected effect of amendment of the measures in Action Plan on the Aquatic Environment II (APAE-II).

Measure	**Reduction in leaching by 2003 (tonnes N)**
Forecast at midterm evaluation	**92,600**
Expected effect of adjustment of APAE-II	
• Wetlands	1,500
• Afforestation	50
• Agri-environmental measures in ESAs	200
• Reduction in bread wheat acreage eligible for N supplement, from 330.000 to 50.000 ha	2,000
• Revision of N norms, 6% catch crops	1,500
• Revision of N norms, winter barley and winter wheat	800
• Revision of N norms, permanent grass	200
• Revision of N norms, grass cutting, undersown grass and set-aside	1,325
Amendment of the APAE-II, total	**7,575**
Total reduction	**100,175**