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Aquatic Environment 2004

State and trends – technical summary

NERI Technical Report, No. 561

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2005

Jens Møller Andersen
Susanne Boutrup
Lars M. Svendsen
Jens Bøgestrand
Ruth Grant
Jens Peder Jensen
Thomas Ellermann
Gunni Ærtebjerg
National Environmental Research Institute

Lisbeth Flindt Jørgensen
Geological Survey of Denmark and Greenland

Mette Wolstrup Pedersen
Danish Environmental Protection Agency

Data sheet

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Authors: J.M. Andersen[1], S. Boutrup[1], L.M. Svendsen[1], J. Bøgestrand[2], R. Grant[2], J.P. Jensen[2], T. Ellerman[3], G. Ærtebjerg[4], L.F. Jørgensen[5], M.W. Pedersen[6]
Departments: [1]Monitoring, Advice and Research Secretariat, [2]Department of Freshwater Ecology, [3]Department of Atmospheric Environment, [4]Department of Marine Ecology, [5]Geological Survey of Denmark and Greenland, [6]Danish Environmental Protection Agency

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Abstract: This report presents the 2003 results of the Danish Aquatic Monitoring and Assessment Programme 1998–2003. The report contains the scientific conclusions as to the state of the groundwater, watercourses, lakes, atmosphere and the marine waters and the pressures upon them. The report is based on the annual reports of each subprogramme prepared by the Topic Centres. The latter reports are based on data collected by the regional authorities and in most cases also reported by them.

Keywords: Action Plan on the Aquatic Environment, state of the environment, groundwater, watercourses, lakes, marine waters, atmospheric deposition, wastewater, discharges, agriculture, nitrogen, phosphorus, pesticides, heavy metals, hazardous substances, oxygen deficit

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For sale at: Ministry of the Environment
Frontlinien
Rentemestervej 8
DK-2400 Copenhagen NV
Tel: +45 7012 0211
frontlinien@frontlinien.dk

Contents

AQUATIC ENVIRONMENT 2004

State and trends – technical summary of the 2003 monitoring results

Water quality and nutrient transport through watercourses are measured at 231 watercourse stations. The photograph shows the monitoring station in the river Funder at Silkeborg.

This scientific summary report presents the 2003 results of the Danish Aquatic Monitoring and Assessment Programme 1998–2003 (NOVA-2003) (*Danish EPA, 2000*).

The report describes the environmental state of the water bodies in 2003 as well as the trends in environmental quality over the period 1989–2003 in relation to changes in the pressures on the aquatic environment.

The primary aim of the scientific summary is to inform the Parliamentary Committee on the Environment and Regional Planning of the results of the 2003 monitoring and of the effects of the regulations and investments specified under the 1987 Action Plan on the Aquatic Environment. In addition, it will provide a national overview to the staff of the state and county institutions who have carried out the monitoring programme, or who work with management of the aquatic environment. Finally, it will enable the public, NGOs and other organizations to obtain key information about the state of the aquatic environment and the trends therein.

The report has been prepared by the National Environmental Research Institute (NERI) in cooperation with the Geological Survey of Denmark and Greenland (GEUS) and the Danish Environmental Protection Agency on the basis of reports from seven Topic Centres.

The Topic Centre reports are available in Danish via the links given in the electronic version of the report.

The Topic Centre reports are based on data collected by the regional authorities and by NERI as regards the atmosphere and the open marine waters. The majority of the data are also reported in the regional reports, which are used when preparing the Topic Centre reports.

AQUATIC ENVIRONMENT 2004 – Background reports (in Danish)

Vandløb 2003.	*Bøgestrand (ed.), 2004.*
Atmosfærisk deposition 2003.	*Ellermann et al., 2004.*
Landovervågningsoplande 2003.	*Grant et al., 2004.*
Grundvandsovervågning 1998-2003.	*GEUS, 2004.*
Marine områder 2003.	*Ærtebjerg et al., 2004.*
Søer 2003.	*Jensen et al., 2004.*
Punktkilder 2003.	*Danish EPA, 2004.*

Summary

The main conclusion of the Danish Aquatic Monitoring and Assessment Programme (NOVA-2003) for the year 2003 is that wastewater discharges of organic matter, nitrogen and phosphorus and nitrogen loss from cultivated land have decreased considerably since 1989 following implementation of the 1987 Action Plan on the Aquatic Environment.

These reductions have led to moderate improvements in ecological and environmental conditions in the lakes and marine waters.

As regards groundwater, a minor decrease in nitrate concentration has been detected in the youngest groundwater.

In watercourses, where environmental quality is mainly determined by the physical conditions and input of organic matter, slight improvements in state have been observed over the past five years.

Due to the low winter precipitation in 2003, nutrient leaching from the soil was particularly low in 2003. Discharges from point sources were also generally lower than in the preceding years.

Despite the improvements, less than half of all water bodies complied with the current quality objectives in 2003.

Sources of nutrient and organic matter pollution

With most sources, the nutrient and organic matter load in 2003 was low compared to a climatically normal year because the precipitation was low. Due to the low precipitation in the winter period, leaching of nitrogen and phosphorus from cultivated land decreased in 2003 because most leaching occurs during periods of high runoff in winter. A further consequence of the low precipitation was that the discharge of water from wastewater treatment plants and urban stormwater outfalls was less than normal.

From the figures for nutrient and organic matter inputs to the aquatic environment (Table 1) it is apparent that the dominant sources of nitrogen loading are leaching from cultivated land and deposition from the atmosphere. The atmospheric nitrogen load derives from combustion processes and from ammonia volatilization from manure in Denmark and abroad. The atmospheric nutrient load is distributed over all the Danish marine waters and is thus of minor significance for the state of the fjords and coastal waters.

In 2003, the phosphorus load to the aquatic environment mainly derived from wastewater, even though good treatment has reduced these discharges to the lowest level yet.

The organic matter load from the various sources of pollution is not directly comparable with the natural background load as the organic matter in wastewater differs in character from that of naturally occurring organic matter. Thus its polluting effect is relatively greater.

Wastewater treatment plants

Removal of organic matter (BOD_5) and the nutrients nitrogen (N) and phosphorus (P) at the wastewater treatment plants is generally very effective. In 2003, 90% of all wastewater underwent organic matter, nitrogen and phosphorus treatment. Since the mid 1980s, discharges of BOD_5, N and P have been reduced by 96%, 81% and 93%, respectively. The wastewater treatment efficiencies for BOD_5 and phosphorus are generally much better than the outlet criteria in the Action Plan on the Aquatic Environment I (APAE I). The majority of the wastewater treatment plants encompassed by the Action Plan's general treatment requirements thus clean the wastewater down to 2–4 mg BOD_5/l and 0.2–0.5 mg P/l. The Action Plan's general treatment requirements for wastewater treatment plants with a capacity exceeding 5,000 PE are a BOD_5 concentration of 15 mg/l and a phosphorus concentration of 1.5 mg P/l. The nitrogen concentration is also generally lower than the general discharge criterion of 8 mg N/l. In 2003, all the wastewater treatment plants encompassed by the requirements of Action Plan on the Aquatic Environment I met the discharge criteria for BOD_5 and phosphorus, while five of the 199 plants subject to the discharge criterion for nitrogen failed to meet it.

AQUATIC ENVIRONMENT 2004 – Table 1

SOURCE APPORTIONMENT 2003	Organic matter (BOD_5) (tonnes/yr)	Nitrogen (tonnes/yr)	Phosphorus (tonnes/yr)
Background loading	5,600	5,400	240
Leaching from agriculture	2,300	40,100	440
Wastewater treatment plants	2,336	3,614	404
Stormwater outfalls	2,050	685	172
Sparsely built-up areas*	3,700	900	220
Industry	3,750	509	33
Freshwater fish farms	3,100	1,120	90
Marine and saltwater fish farms	approx. 1,560	296	32
Total	**approx. 24,000**	**52,680**	**1,629**
Via the atmosphere to Danish marine waters	approx. 0	approx. 124,000	approx. 400

Table 1 Total inputs of organic matter and nutrients to the Danish aquatic environment in 2003 apportioned by source. * Wastewater from rural properties outside the sewerage catchment (data from *Danish EPA, 2004*, *Bøgestrand (ed.), 2004* and *Ellermann et al., 2004*).

Enterprises

Industrial enterprises with their own wastewater outfall have generally reduced their proportion of the total discharges to the same extent as the wastewater treatment plants. Nutrient and organic matter loading from freshwater fish farms and marine fish farms have also decreased slightly, although the reduction is relatively smaller than for the wastewater treatment plants and industry.

Leaching from cultivated land

Leaching of nutrients from cultivated land is determined by the agricultural practice, the amount of fertilizer applied and the nature of the land. The amount of nitrogen applied in the form of commercial fertilizer has decreased from 395,000 tonnes in 1985 to 196,000 tonnes in 2003, while the amount of nitrogen applied in the form of manure and sewage sludge has remained largely unchanged. This has led to a reduction in nitrogen leaching from cultivated land over the period 1989–2003. The measured mean reduction in the nitrate concentration in root zone water is 38% in clayey soils and 50% in sandy soils, although the results are subject to considerable variation.

The amount of phosphorus applied in the form of commercial fertilizer has decreased from approx. 40,000 tonnes in 1990 to approx. 13,000 tonnes in 2003, and manure is now the dominant form of phosphorus fertilizer in Denmark. On livestock holdings, considerably more phosphorus is still applied than is removed in the crops. The amount of phosphorus leaching from cultivated land varies considerably from area to area and from year to year depending on the precipitation. No trend has been detected in the losses of total phosphorus from cultivated land.

Atmospheric deposition of nitrogen

Nitrogen deposition on the land typically varies from 12 to 24 kg N/ha/yr and is greatest in areas with large livestock herds and high precipitation. Deposition on marine waters is lower, i.e. 7–17 kg/N/yr, among other reasons because of the greater distance to the sources of pollution and the lower precipitation. The main sources of the nitrogen are nitrogen oxide formation in combustion processes and ammonia volatilization from manure. The majority of the nitrogen deposited on the marine waters derives from foreign sources, while Danish sources account for a greater proportion of that deposited on the landmass. The Danish proportion is greatest in Jutland (38%), where it mainly derives from ammonia volatilization from agriculture. It is estimated that total atmospheric deposition of nitrogen on the Danish marine waters and landmass has decreased by approx. 21% over the period 1989–2003.

Groundwater

In 2003, total groundwater abstraction amounted to 634 million m^3, corresponding to a 39% reduction in abstraction since 1989. Of the total, 64% was abstracted for the public water supply. The nitrate concentration is highest in the uppermost groundwater formed within the past few decades. The data for 2003 show that the nitrate concentration in the youngest groundwater has been decreasing since 1989. In 2003, the mean nitrate concentration in the water percolating down towards the aquifers from cultivated land was close to 50 mg nitrate/l, which is the limit value for nitrate in drinking water. In oxic aquifers the nitrate concentration can still be at this level, whereas the phosphorus concentration in such aquifers is low. In anoxic and usually deeper aquifers, in contrast, the nitrate has been converted to atmospheric nitrogen, and the nitrate concentration is therefore very low. Moreover, the phosphorus concentration is high because part of the naturally occurring phosphorus in the soil dissolves under anoxic conditions.

The frequency with which pesticides are detected in connection with groundwater monitoring has remained at the same level in recent years, while the proportion of samples exceeding the limit value for drinking water has been increasing slightly. As regards waterworks wells, in contrast, the proportion of samples exceeding the limit value for drinking water has decreased, probably due to the cessation of abstraction from wells with high pesticide concentrations.

Quality objective compliance

At the groundwater monitoring sites the nitrate concentration exceeds the limit value for drinking water in 16% of the filters. The corresponding figure for the waterworks wells was only 1% because wells with a nitrate concentration exceeding 50 mg/l are not used for abstracting water for the drinking water supply.

In 2003, the pesticide concentration exceeded the limit value for drinking water in approximately 10% of the filters analysed at the groundwater monitoring sites. The proportion of samples exceeding the limit value has been increasing slightly in recent years. As regards waterworks wells, in contrast, the proportion has decreased from approximately 10% in 1998 to approximately 5% in 2003.

Lakes

In general, the environmental state of the monitoring lakes that receive wastewater was better in 2003 than in 1989. Among other things, this is reflected in a moderate increase in the mean Secchi depth in the lakes and a corresponding reduction in algal biomass in the water. Improvement has taken place in lakes where phosphorus input from wastewater has been reduced. In the other lakes, no improvement has generally been seen. In these lakes the main source of phosphorus input is normally leaching from cultivated land in the catchment, which has not been reduced. With many lakes, wastewater discharges from rural properties outside the sewerage catchment (sparsely built-up areas) also comprise a major source of pollution.

The occurrence of pesticides and other hazardous substances in the eight lakes investigated is generally minor.

Quality objective compliance

Of the 31 lakes investigated, seven to eight met their quality objectives in 2003. The state of some of the lakes will improve when internal release of phosphorus from previous wastewater inputs ceases. With the majority of the lakes, however, it will only be possible to meet the politically determined quality objectives if phosphorus inputs from cultivated land and sparsely built-up areas are also reduced.

Watercourses

The environmental state of Danish watercourses is particularly affected by the physical changes in their natural courses that have occurred as a result of damming and channelization, and which still occur as a result of watercourse maintenance. In earlier times, many watercourses were also polluted with organic matter from wastewater, but this pollution has been reduced to a much lower level through wastewater treatment since the 1970s.

The biological quality of the watercourses has improved over the last decades. The present station network and assessment method have remained unchanged since 1999. The measurements show that the proportion of the watercourses in which the macroinvertebrate fauna is unaffected or only slightly affected has increased from just under 35% in 1999 to just over 44% in 2003. Biological quality is generally lowest in the small watercourses and in watercourses east of the Great Belt, and best on Funen and in Jutland.

The biological conditions in Danish watercourses are only slightly dependent on the nutrient concentration in the water, but the watercourses transport the nutrients to lakes and marine waters, where nutrients are the main pollutant. The concentrations of nitrogen and phosphorus in Danish watercourses have generally decreased since 1989. Thus the watercourse nitrogen concentration in 2003 was approx. 2 mg N/l or approx. 30% less than in 1989, mainly due to reduced leaching from cultivated land. The decrease began early in the 1990s. The phosphorus concentration has decreased by just over 40% since 1989, but the reduction probably started earlier as a result of the introduction of phosphorus removal from wastewater prior to 1989.

A number of pesticides and their degradation products have been detected in watercourses. The substances most frequently detected are the active ingredient of Roundup, glyphosate, and its degradation product AMPA. Another frequently detected substance is BAM, a degradation product of the active ingredient of pesticides such as Casoron, which is presently prohibited. Other hazardous substances occur so infrequently in the investigated watercourses that no general picture can be formed.

Quality objective compliance

Of the watercourses investigated, 51% met their quality objective in 2003. In order for the other watercourses to be able to meet their politically determined quality objectives, physical conditions will have to be changed to make them more resemble natural conditions with varying types of streambed. In addition, many small watercourses are still polluted by inadequately treated wastewater, especially from rural properties outside the sewerage catchment. A naturally small slope and dry-out in the summer often limit the possibilities for a clean water fauna, however, especially in eastern Denmark.

Nutrient inputs to the sea

Pollution pressure on the Danish coastal waters is largely attributable to nutrient loading from land-based sources. Phosphorus loading has decreased considerably due to effective treatment of wastewater (Figure 1). The total nitrogen and phosphorus inputs via diffuse loading are highly correlated to freshwater runoff via the watercourses. As diffuse loading is the dominant source of nitrogen, the total nitrogen input varies markedly with precipitation and freshwater runoff in the individual year. A statistically reliable reduction in nitrogen input to the sea can only be demonstrated by correcting the measured nitrogen inputs for interannual variation in freshwater runoff. After correction for variation in freshwater runoff, the reduction in total nitrogen input to the sea over the period 1989–2003 is 43%. The corresponding reduction in total phosphorus input is 81%.

AQUATIC ENVIRONMENT 2004 – Figure 1

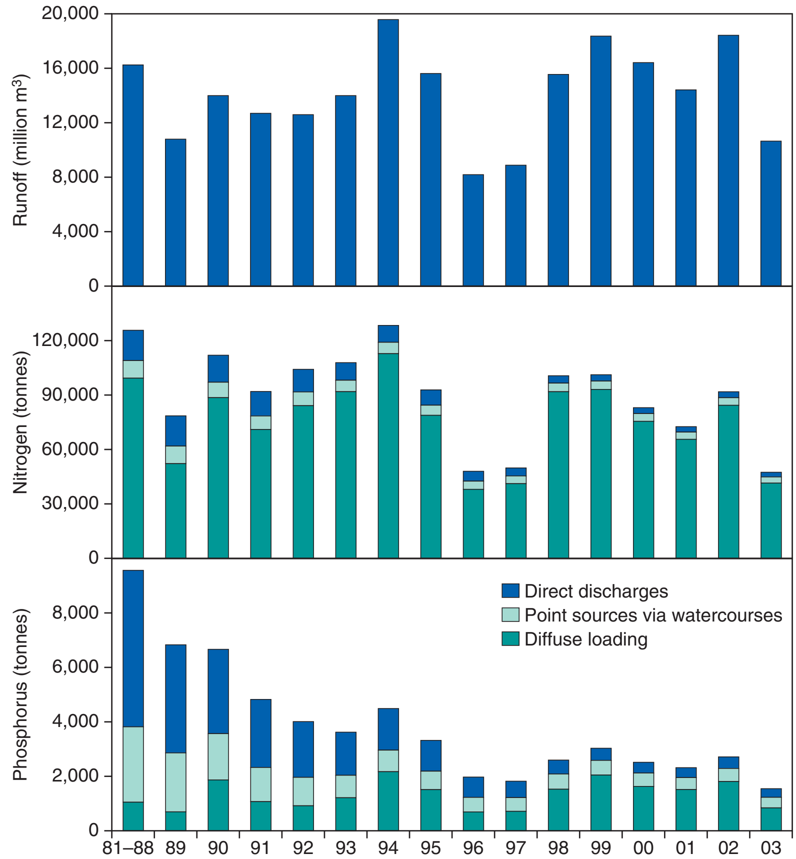


Figure 1 Freshwater runoff and total inputs of nitrogen and phosphorus via riverine runoff and direct wastewater discharges to Danish marine waters over the period 1989–2003 compared with the mean for the period 1981–1988 *(Bøgestrand (ed.), 2004).*

In the absence of correction for annual runoff, no statistically significant reduction in nitrogen input to Danish marine waters can be discerned. This is due to the fact that freshwater runoff and hence nitrogen leaching were higher than normal in each of the years 1998–2002. A statistically significant reduction in phosphorus input can be discerned, however, also without correction for runoff.

Marine waters

The main pollution pressure on Danish marine waters results from inputs of nitrogen and phosphorus to the sea from land-based sources and via the atmosphere. The shallow Danish marine waters are more vulnerable to eutrophication than the majority of other marine waters elsewhere in the world because water exchange with the open sea is often limited, and because stratification of the water masses often limits the input of oxygen to the bottom water. The most strongly polluted of the marine waters are those with a high freshwater input and little water exchange with adjoining marine waters.

There are initial signs of improvement in the state of the marine waters. Nutrient concentrations in the fjords and coastal waters have begun to decrease, and algal production is increasingly being limited by a lack of nitrogen and phosphorus. Secchi depth is also tending to increase in the fjords and coastal waters, and algal biomass and production have decreased since the 1980s. These improvements have not yet led to increases in the distribution of submerged aquatic vegetation (including eelgrass) or benthic invertebrates. Neither are there any signs of general improvements in oxygen content in the bottom water in the fjords and coastal waters or in the open marine waters.

A number of hazardous substances were detected in the sediment of the fjords and inner marine waters investigated in 2003. These include tributyl tin (TBT), which has been used as an antifouling agent in hull paints. In the marine environment, TBT affects the reproductive characteristics of gastropod molluscs and in the worst case causes sterility. In 2003, the effects of TBT on gastropod molluscs were found to be widespread in the marine waters, even in open seas such as the North Sea and the Skagerrak.

Quality objective compliance

The politically determined objective that marine flora and fauna may only be slightly affected by pollutant inputs is generally considered to be fulfilled in the open parts of the North Sea and the Skagerrak. In the northern part of the Kattegat, the objective is considered close to being met. In the other marine waters the objective has not yet been met, primarily because high nutrient inputs have enhanced algal biomass. In some fjords and coastal waters the lack of quality objective compliance is also attributable to the presence of hazardous substances. Fulfilment of the objectives requires further reductions in nutrient inputs and in some cases, also of inputs of hazardous substances and heavy metals.

1 Introduction

1.1 Organization and content of the monitoring programme

The majority of the monitoring is carried out by the regional authorities. In 2003, NERI was responsible for monitoring at the extensive marine stations, for measurement and calculation of atmospheric deposition and for measurement of water flow at the 22 national watercourse stations for which long time series exist.

Monitoring stations in the NOVA-2003 programme

The locations of the monitoring stations and sites encompassed by the primary subprogrammes of the Danish Aquatic Monitoring and Assessment Programme (NOVA-2003) are indicated in Figure 1.1. The stations for wastewater discharge monitoring, for waterworks well control and for assessing watercourse biological quality are not shown, however.

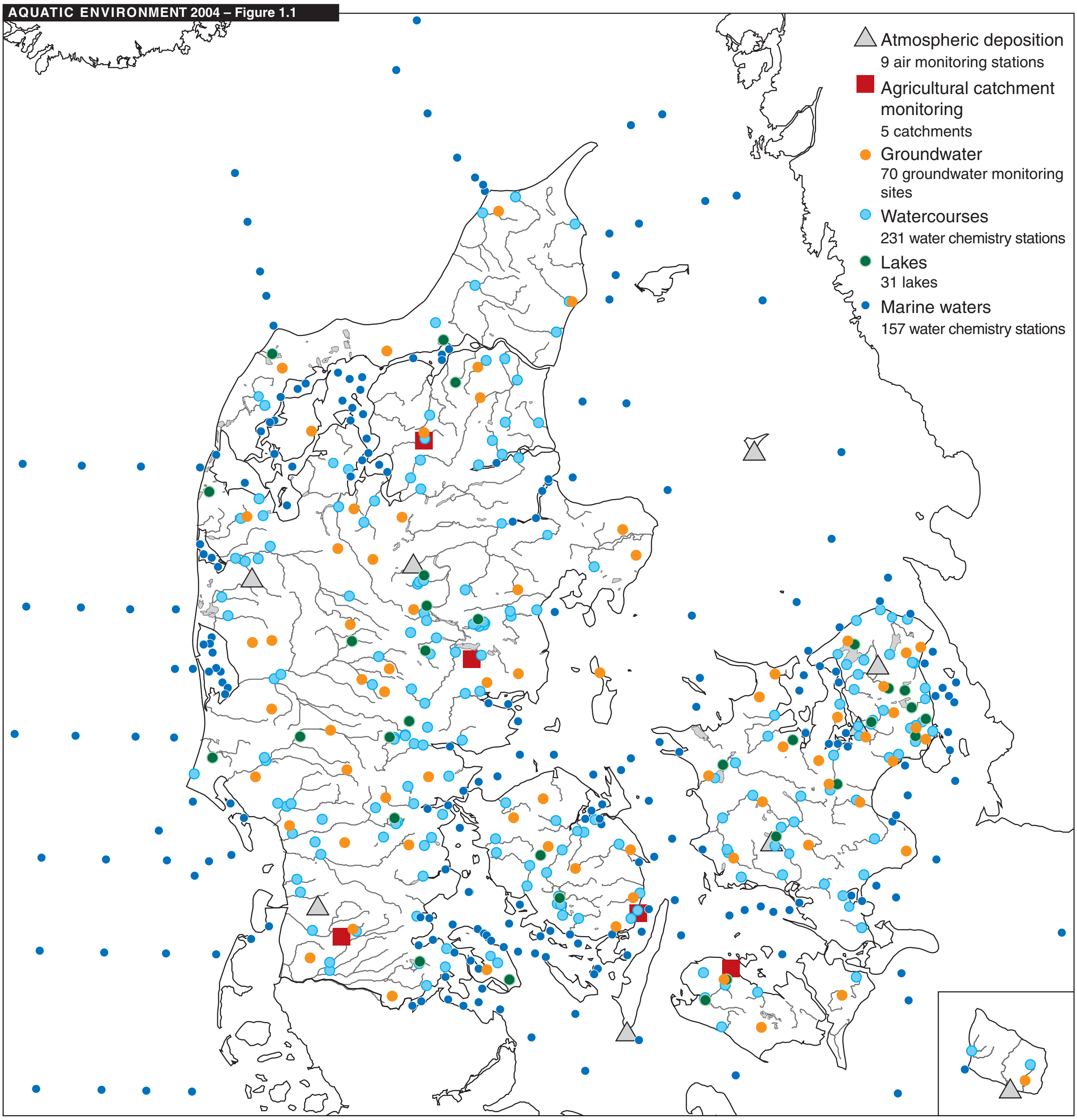


Figure 1.1 NOVA-2003 monitoring locations for selected parts of the monitoring programme.

Further information about NOVA-2003
The monitoring programme is described in detail elsewhere (*Danish EPA, 2000*) and on NERI's website at http://www.dmu.dk/NR/rdonlyres/4D0E7938-178C-47A4-AEBA-950F3780A2CC/0/NOVADKUK118DRAFTTranslation.pdf.

1.2 Climate and freshwater runoff

Precipitation
In 2003, precipitation amounted to 630 mm, 12% less than the normal of 712 mm (1961–1990) (Table 1.1) and fully 235 mm less than in 2002. The dry year 2003 came after five years of greater than normal precipitation.

Temperature and sunshine
The annual mean temperature was 8.7°C in 2003, 1°C above the normal temperature (Table 1.1). Only February and October were colder than normal, while July, August, November and December were warmer than normal. With a mean of 1,869 hours of sunshine, 2003 was the second sunniest year since measurements started in 1920.

Freshwater runoff
Freshwater runoff from Denmark in 2003 is calculated to be 10,700 million m^3, corresponding to 248 mm or 24% less than the normal of 326 mm (1971–2000). Runoff was above normal during the period May–July and considerably below normal in February–April and in the fourth quarter of 2003 (Figure 1.2).

As with precipitation, freshwater runoff exhibits considerable geographic variation (Figure 1.3). Runoff was lowest to the marine waters in the southern Belt Sea, the Baltic Sea and the Øresund (100–200 mm) and highest to the marine waters in the North Sea (300–400 mm).

AQUATIC ENVIRONMENT 2004 – Table 1.1

Period	Temperature (°C)	Precipitation (mm)	Runoff (mm)	Runoff (million m^3)
2003	8.7	630	248	10,700
1989–2003	8.5	730	326	14,000
Normal	7.7	712	326	14,000

Tabel 1.1 Annual mean temperature, precipitation and freshwater runoff in 2003 and 1989–2003 compared with the normal for the period 1961–1990 (1971–2000 in the case of freshwater runoff) (after *Bøgestrand (ed.), 2004* and *Cappelen & Jørgensen, 2004)*.

AQUATIC ENVIRONMENT 2004 – Figure 1.2

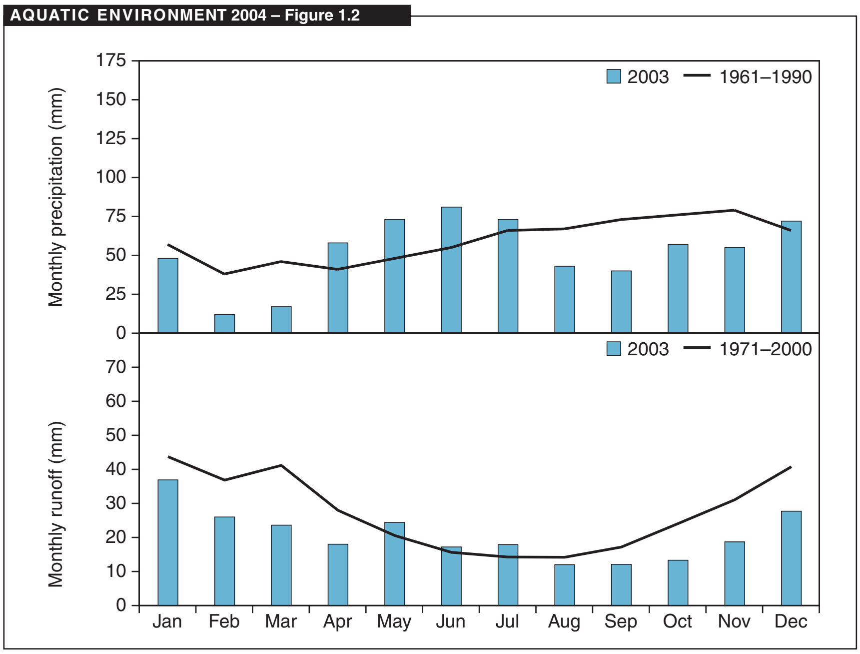


Figure 1.2 Monthly precipitation in Denmark in 2003 compared with the normal for the period 1961–1990. Monthly mean freshwater runoff in 2003 compared with the mean for the period 1971–2000 (*Bøgestrand (ed.), 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 1.3

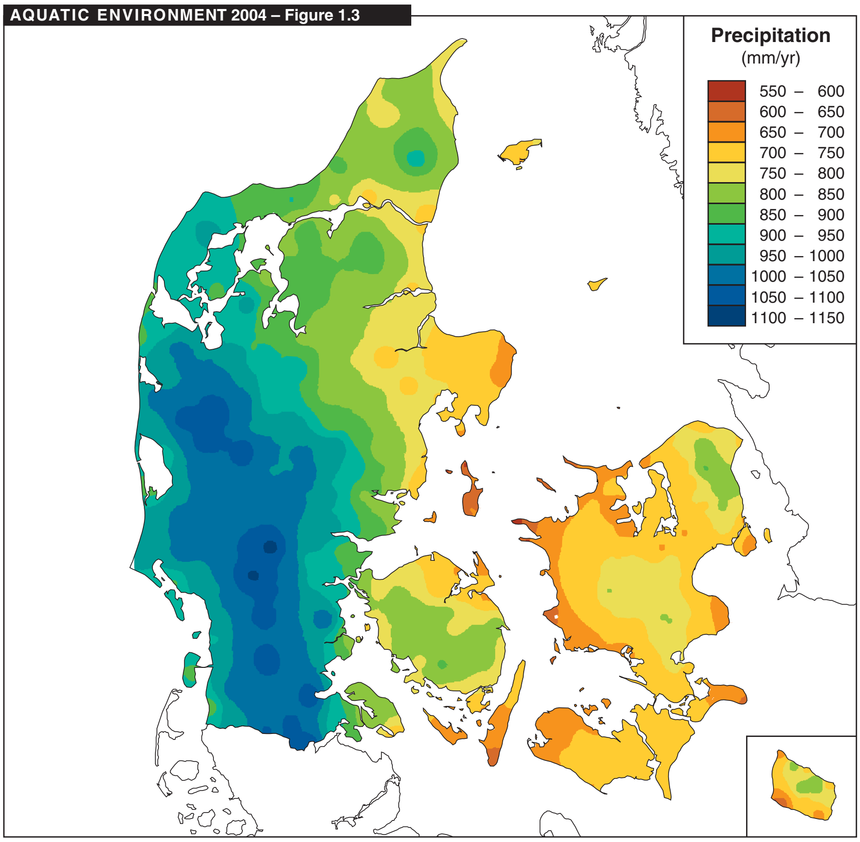


Figure 1.3 Annual mean precipitation for the period 1971–98 (*Scharling, 2000*).

1.3 Trend in climate and freshwater runoff

On average over the past 15 monitoring years, both annual precipitation and mean temperature have exceeded the normal for the period 1961–1990 – in particular during the winters.

Freshwater runoff correlates with the precipitation (Figure 1.4). This also applies to the groundwater level, although with a temporal delay. In dry years the groundwater resource diminishes, and in wet years it builds up. After the relative dry year of 2003 the groundwater level is close to normal.

AQUATIC ENVIRONMENT 2004 – Figure 1.4

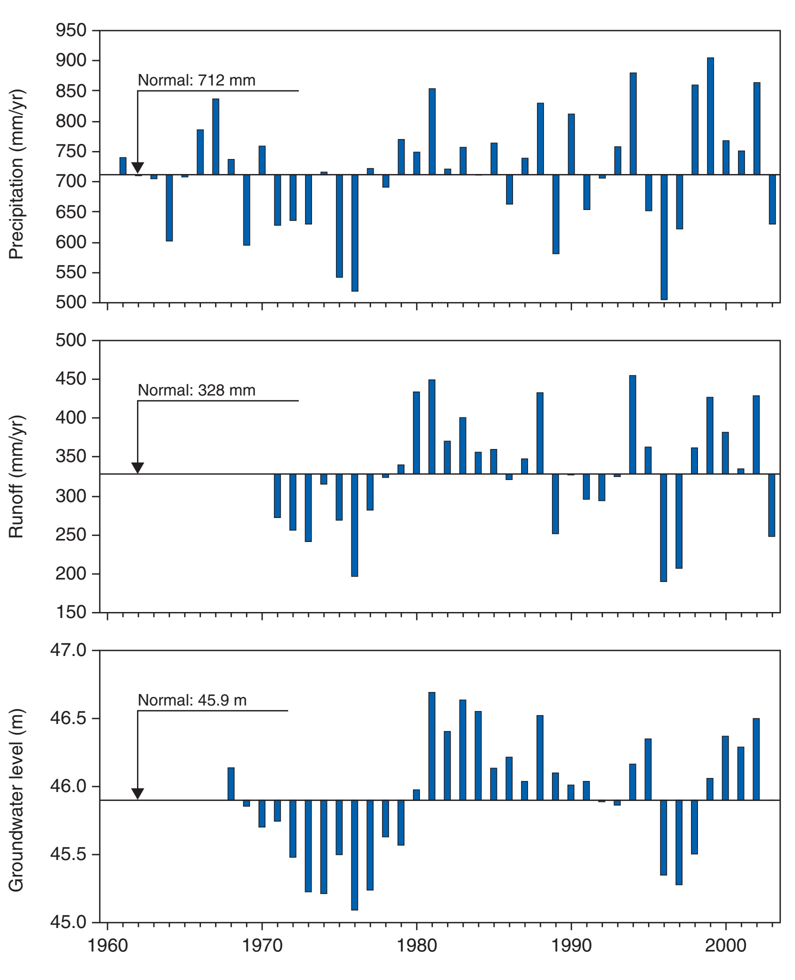


Figure 1.4 Annual mean precipitation and runoff in Denmark and annual mean groundwater level at Karup over the period 1961–2003 shown relative to the mean (normal).

2 Sources of organic matter and nutrient pollution

Organic matter and nutrients occur naturally in the aquatic environment, including in the groundwater. They are a precondition for aquatic life, but are concomitantly the main source of pollution of our water bodies. When the amount of these substances greatly exceeds the natural input, the aquatic flora and fauna change. The sources of this pollution (eutrophication) are subdivided into point sources (wastewater) and diffuse sources.

2.1 Pollution from the individual types of source

The total inputs of organic matter, nitrogen and phosphorus to watercourses, lakes and marine waters are shown apportioned by source in Table 2.1. As is apparent, there are many different significant anthropogenic sources of organic matter and phosphorus, while the dominant sources of nitrogen are atmospheric deposition and leaching from cultivated land. Inputs from adjoining marine waters derived in part from foreign sources are also important, but are not included in Table 2.1.

The majority of the loads shown in Table 2.1 have been determined by measurement and hence are reasonably reliable. Some of the loads, especially for organic matter, are estimates, however.

AQUATIC ENVIRONMENT 2004 – Table 2.1

SOURCE APPORTIONMENT 2003	Organic matter (BOD_5) (tonnes/yr)	Nitrogen (tonnes/yr)	Phosphorus (tonnes/yr)
Background loading	5,600	5,400	240
Leaching from agriculture	2,300	40,100	440
Wastewater treatment plants	2,336	3,614	404
Stormwater outfalls	2,050	685	172
Sparsely built-up areas*	3,700	900	220
Industry	3,750	509	33
Freshwater fish farms	3,100	1,120	90
Marine and saltwater fish farms	approx. 1,560	296	32
Total	**approx. 24,000**	**52,680**	**1,629**
Via the atmosphere to Danish marine waters	approx. 0	approx. 124,000	approx. 400

Table 2.1 Total inputs of organic matter and nutrients to the Danish aquatic environment in 2003 apportioned by source. * Wastewater from rural properties outside the sewerage catchment (data from *Danish EPA, 2004*, *Bøgestrand (ed.), 2004* and *Ellermann et al., 2004*).

Significance of the sources of pollution

The figures in Table 2.1 illustrate the general relationship between the magnitude of the various sources of organic matter and nutrient pollution at the national level and hence also the general significance of the individual sources. The table cannot be used to illustrate the significance of the individual sources for specific water bodies, however. There are two main reasons for this. One is that the sensitivity of the various types of water body to inputs of these substances differs. For example, an increased nitrate concentration in a watercourse is unlikely to affect the flora and fauna in the watercourse, whereas the same increase would lead to a significant change in marine waters and in certain lakes. The other reason is that the source apportionment shown for the country as a whole in Table 2.1 will not resemble that for a specific water body. For example, virtually all the inputs from industrial sources take place directly to marine waters, while all inputs from freshwater fish farms take place to watercourses in Jutland.

In order to be able to determine what environmental improvements can be expected from measures to curtail organic matter and nutrient loading it is necessary to determine source apportionment for the individual water bodies. Calculations of the possible changes in inputs will then enable assessment/calculation of the probable effects that these changes will have on the water body.

As is apparent from Table 2.1, atmospheric inputs to Danish marine waters as a whole are considerable. They are of much less importance for inland waters and coastal waters, however, where the other, local sources are more important.

The individual sources and the trend in inputs from them are described in more detail in Chapters 3–5.

3 Point sources

The point sources encompass discharges from wastewater treatment plants, industry, freshwater fish farms, sparsely built-up areas, stormwater outfalls and marine fish farms. The monitoring results are reported in detail elsewhere (*Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 3.1

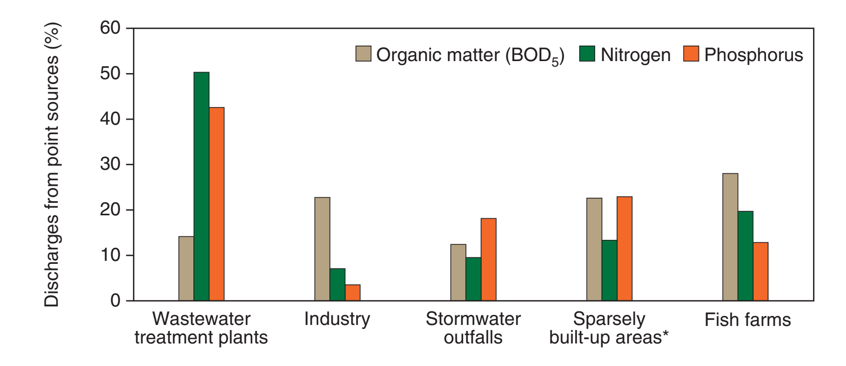


Figure 3.1 Organic matter (BOD_5), nitrogen (Total N) and phosphorus (Total P) discharges apportioned by source in 2003. The certainty of the values is greatest for wastewater treatment plants and industry. The values for the others are based on calculations and are less certain.
* Wastewater from rural properties outside the sewerage catchment (*Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 3.2

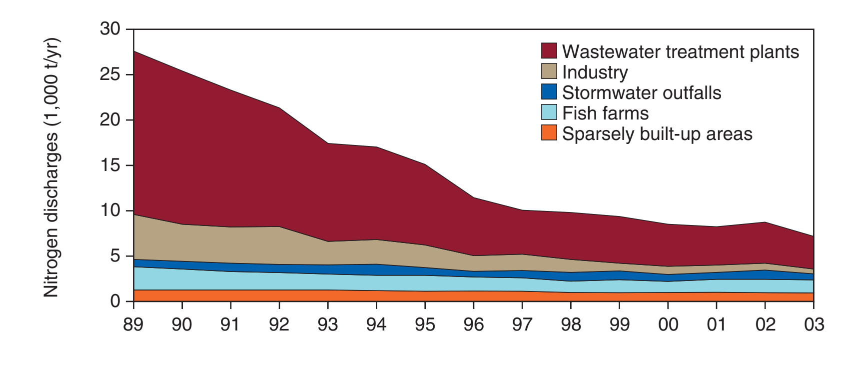


Figure 3.2 Discharge of nitrogen from point sources over the period 1989–2003 (*Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 3.3

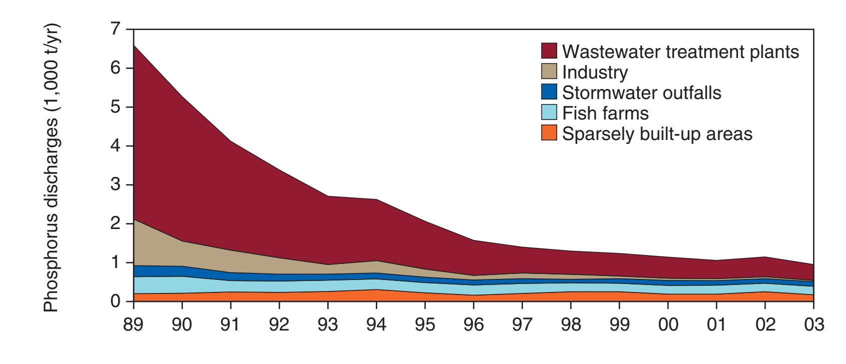


Figure 3.3 Discharges of phosphorus from point sources over the period 1989–2003 (*Danish EPA, 2004*).

Total discharges in 2003

Total discharges from point sources in 2003 amounted to 16,500 tonnes organic matter (BOD_5), approx. 7,200 tonnes nitrogen and approx. 950 tonnes phosphorus. The source apportionment of these discharges is shown in Figure 3.1. The wastewater treatment plants account for the largest proportion of the nitrogen and phosphorus discharges, while freshwater and marine fish farms, industry and sparsely built-up areas (rural properties outside the sewerage catchment) account for the largest proportions of organic matter (BOD_5).

The majority of the point sources discharge into the inner marine waters or their catchments.

Trend in point sources

The overall reduction in discharges of nitrogen is largely attributable to reductions in discharges from industry and wastewater treatment plants. The trend in discharges of nitrogen is shown for the various point sources in Figure 3.2. The total discharge has decreased from approx. 27,600 tonnes in 1989 to approx 7,200 tonnes in 2003. The total discharge of phosphorus from point sources has decreased from approx. 6,600 tonnes in 1989 to 950 tonnes in 2003. Discharges from sparsely built-up areas and from freshwater and marine fish farms have also decreased (Figure 3.3).

3.1 Wastewater treatment plants

The total input to municipal wastewater treatment plants in 2003 corresponded to 8,6 million PE, while the total treatment capacity was 12.6 million PE (1 PE is the amount of organic matter and nutrients in the untreated wastewater from 1 person).

The number of wastewater treatment plants continues to decrease. In 2003, there were 1,204 plants, of which approx. 265 are encompassed by the general treatment requirements stipulated in Action Plan on the Aquatic Environment I (15 mg BOD_5/l, 8 mg N/l and 1.5 mg P/l). These wastewater treatment plants treat 90% of all urban wastewater in Denmark. In order to meet the environmental quality objectives stipulated for individual water bodies in the Regional Plans the Counties often impose more rigorous treatment requirements, especially regarding the discharge of organic matter to watercourses and of phosphorus in the catchments of lakes and fjords. This also applies to plants with a capacity under 5,000 PE, which is the limit at which the general requirements stipulated in Action Plan on the Aquatic Environment I enter into force.

Details of the organic matter and nutrient concentrations in the treated wastewater from each wastewater treatment plant are available in *Danish EPA, 2004*. The tables in that report show that the mean concentrations in the wastewater discharged by the majority of the plants are 2–4 mg/l for BOD_5 and 0.2–0.5 mg/l for phosphorus.

Total discharge from wastewater treatment plants

Discharges were slightly lower in 2003 than in the preceding years. The lower precipitation in 2003 has probably helped reduce the discharges. The quality of the treated wastewater is far better than the general requirements stipulated in Action Plan on the Aquatic Environment I. The figures in Table 3.1 include all wastewater treatment plants, i.e. both those that are and are not encompassed by the Action Plan treatment requirements (15 mg BOD_5/l, 8 mg N/l and 1.5 mg P/l).

Treatment efficiency

In 2003, data on the organic matter and nutrient inputs were reported for just over half of the wastewater treatment plants. Table 3.1 shows the overall mean concentrations of BOD_5, total nitrogen and total phosphorus in the wastewater input to the wastewater treatment plants. The general level of treatment can be judged by comparing the inflow concentrations with the corresponding mean concentrations in the treated wastewater also shown in Table 3.1. Treatment efficiency is 98–99% for easily degradable organic matter (BOD_5), approx. 93% for phosphorus and approx. 88% for nitrogen.

Compliance with discharge criteria

In 2003, approx. 265 wastewater treatment plants were encompassed by the treatment requirements stipulated in Action Plan on the Aquatic Environment I. All the plants met the discharge criteria for organic matter (BOD_5) and phosphorus, while five of the plants did not meet the discharge criterion for nitrogen concentration.

Trend in discharges

The total discharges of BOD_5, nitrogen and phosphorus prior to adoption of Action Plan on the Aquatic Environment I (i.e. the mid 1980's) and for each of the years 1989 to 2003 are shown in Figure 3.4 together with the Action

AQUATIC ENVIRONMENT 2004 – Table 3.1

WWTPs 2003	Organic matter (BOD_5)		Nitrogen		Phosphorus	
	(tonnes/yr)	(mg/l)	(tonnes/yr)	(mg N/l)	(tonnes/yr)	(mg P/l)
Discharges in 2003	2,336	3.8	3,614	5.9	404	0.66
Content in untreated urban wastewater	-	308	-	49	-	10

Table 3.1 Total discharges from wastewater treatment plants (WWTPs) with a capacity exceeding 30 PE in 2003. The values give the total discharge in tonnes/yr and the overall water volume-weighted mean concentration in mg/l. In total, 611 million m³ of wastewater were discharged. The corresponding concentrations in untreated urban wastewater are shown for comparison (*Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 3.4

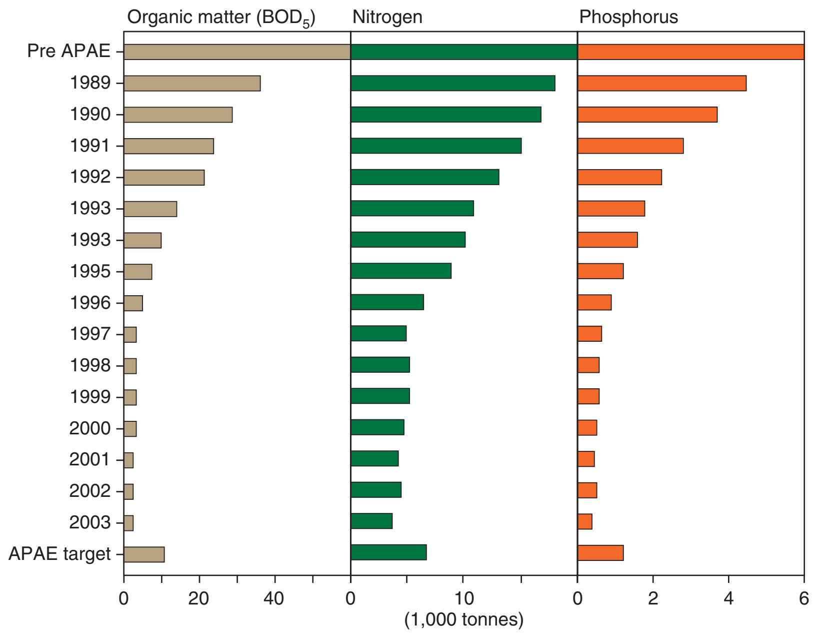


Figure 3.4 Trend in discharges from wastewater treatment plants over the period 1989–2003 shown together with the level prior to the Action Plan on the Aquatic Environment (APAE) and the APAE target (*Danish EPA, 2004*).

Plan discharge targets. It can be seen that discharges of BOD_5 and phosphorus in particular are considerably below the targets set in the Action Plan.

The reduction from the level prior to the Action Plan up until 2003 is 96% for BOD_5, 81% for nitrogen and 93% for phosphorus.

3.2 Industry and fish farms

In 2003, measurements or calculations of discharges were made for 179 enterprises with separate discharges, 347 freshwater fish farms, 12 saltwater fish farms and 23 marine fish farms. All the freshwater fish farms are located on watercourses in Jutland. The saltwater fish farms lie along the coast and pump in seawater, while the marine fish farms are comprised of offshore net cages.

AQUATIC ENVIRONMENT 2004 – Table 3.2

SEPARATE WASTEWATER DISCHARGES FROM ENTERPRISES 2003	Organic matter (BOD_5) (tonnes/yr)	Total nitrogen (tonnes/yr)	Total phosphorus (tonnes/yr)
Industry	3,757	509	33
Freshwater fish farms	3,098	1,119	90
Saltwater fish farms	-	56	6
Marine fish farms	1,560	241	26
Total	**approx. 8,400**	**1,925**	**155**

Table 3.2 Discharges of degradable organic matter and nutrients from enterprises with separate discharges in 2003. No value is given for discharges of organic matter from saltwater fish farms as the calculated discharge is uncertain (*Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 3.5

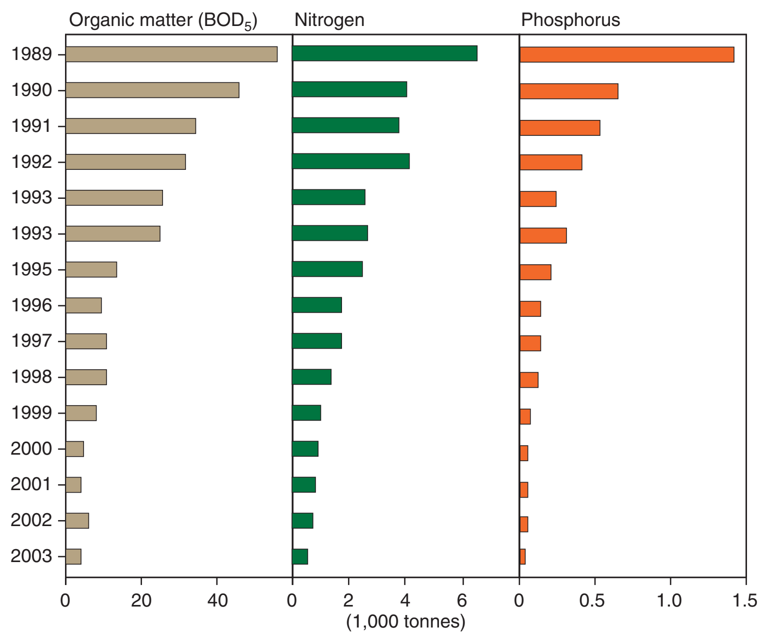


Figure 3.5 Trend in discharges of organic matter (BOD_5), nitrogen and phosphorus from enterprises with separate industrial discharges over the period 1989–2003 (*Danish EPA, 2004*).

Discharges in 2003

The total discharges of organic matter and nutrients from enterprises with separate discharges are given in Table 3.2. Industry and fish farms account for roughly equal proportions of the degradable organic matter discharged. The discharges of nitrogen and phosphorus derive mainly from freshwater fish farms. The majority of these discharges run into lakes or fjords, which are vulnerable to nutrient inputs.

Discharges from industry

The amounts of organic matter and nutrients discharged in 2003 are given in Table 3.2. The majority (80%) of the organic matter (BOD_5) derived from the sugar industry, with a further 15% being accounted for by the fishmeal industry and the remainder of the fish processing industry. The main industrial discharges of nitrogen came from the fish processing industry and from waste processing plants and waste depositories, while the phosphorus discharges mainly came from sugar factories, the fish processing industry and the chemicals industry. The individual discharges are detailed in *Danish EPA, 2004*.

Since 1989, discharges of organic matter and nutrients from these industries have decreased markedly. BOD_5 discharge has been reduced by 93%, nitrogen discharge by 92%, and phosphorus discharge by 98%. These reductions have largely been achieved through changed production conditions and wastewater treatment at the enterprises. However, a large part of the reduction is due to the fact that the wastewater is led to a municipal wastewater treatment plant or to closure of enterprises.

The total discharge of BOD_5 has decreased by 21% compared with 2002, and both nitrogen and phosphorus discharges have been reduced by 33%.

The trend in total discharge from industry over the period 1989–2003 is shown in Figure 3.5.

Discharges from fish farms

The calculated discharges from freshwater fish farms, saltwater fish farm (land-based fish farms that pump in seawater) and marine fish farms (production facilities in the sea) are given in Table 3.2.

Since 1989, theoretical principles have been used to calculate the total discharges from freshwater fish farms. The calculations show that since 1989, discharges of BOD_5 and nitrogen from freshwater fish farms have decreased by approx. 50%, while discharges of phosphorus have decreased by approx. 60%.

Discharges from saltwater fish farms and marine fish farms have also decreased, but to a much lesser extent than for freshwater fish farms.

In 2003, the discharges were calculated on the basis of concrete measurements at just under 150 relatively large and medium-sized freshwater fish farms that together produced approx. 16,750 tonnes of fish in 2003 out of a total production of 29,400 tonnes in Danish freshwater fish farms. Based on the measurements made the discharge from these freshwater fish farms is calculated to be approx. 942 tonnes BOD_5, 398 tonnes nitrogen and 34 tonnes phosphorus.

The measurement results from these freshwater fish farms show that the calculated values for discharge of organic matter (BOD_5) are greater than the real discharge.

3.3 Discharges from sparsely built-up areas

Discharges from rural properties outside the sewerage catchment (sparsely built-up areas) account for a large proportion of the pollution load on many lakes and small watercourses. The total discharges from sparsely built-up areas are calculated from knowledge of the treatment methods used (*Danish EPA, 2004*). The actual discharges to inland waters also depend on the local conditions around the outfall, and the calculated discharges should thus be considered the potential discharges. The County Regional Plans stipulate where treatment of wastewater from sparsely built-up areas is to be improved in order that the quality objectives for water bodies can be met. Of the approx. 350,000 dwellings outside the sewerage catchment, wastewater treatment is to be improved at approx. 100,000.

4 Nutrients from cultivated land

Eutrophication of Danish water bodies is mainly attributable to the nitrogen and phosphorus that leach from cultivated land. Total nutrient leaching is determined from measurements in agricultural monitoring catchments and measurements of nutrient transport in watercourses. (For the distribution of monitoring stations see Figure 1.1). The measurements are coupled with information on agricultural practice, including fertilizer use (*Grant et al., 2004*).

4.1 Nitrogen

Nitrogen consumption in agriculture

Nationwide consumption of commercial fertilizer has decreased from 395,000 tonnes N in 1990 to 196,000 tonnes N in 2003. Over the same period, the amount of nitrogen applied as manure has decreased from 244,000 tonnes N to 237,000 tonnes N. The amount of nitrogen removed in the crops has varied during the period depending on the year's crop (Figure 4.1). The total surplus in the field balance has decreased from 375,000 tonnes N in 1990 to 247,000 tonnes N in 2003, a reduction of 34%.

Part of the reduction is due to the fact that some arable land is no longer cultivated. If the surplus is calculated on a per hectare basis, the surplus has decreased by 31% over the period 1990–2003. In 2003, the surplus was 93 kg N/ha.

The field surplus of nitrogen is generally greatest on cattle holdings and least on crop holdings. Moreover, there is a close correlation between the livestock density and the field surplus of nitrogen (Figure 4.2).

Agricultural monitoring catchments compared with the remainder of Denmark

In 2003, the total nitrogen input to the agricultural monitoring catchments corresponded to the input at the national level. The recorded harvest was somewhat greater in the agricultural monitoring catchments, however, and the reduction in the nitrogen surplus was therefore greater (Table 4.1).

Nitrogen concentration in the water under the fields

The nitrogen concentration is highest in the water in the root zone under the fields. The nitrogen concentration decreases markedly from the root zone down into the upper groundwater. This is due to the fact that nitrogen is mainly in the form of nitrate, and that nitrate is converted to atmospheric nitrogen in anoxic parts of the soil. Deeper in the groundwater the soil layers will normally be reducing (anoxic), and here the nitrogen concentration will be reduced further, often to under 1 mg N/l (Figure 4.3).

AQUATIC ENVIRONMENT 2004 – Figure 4.1

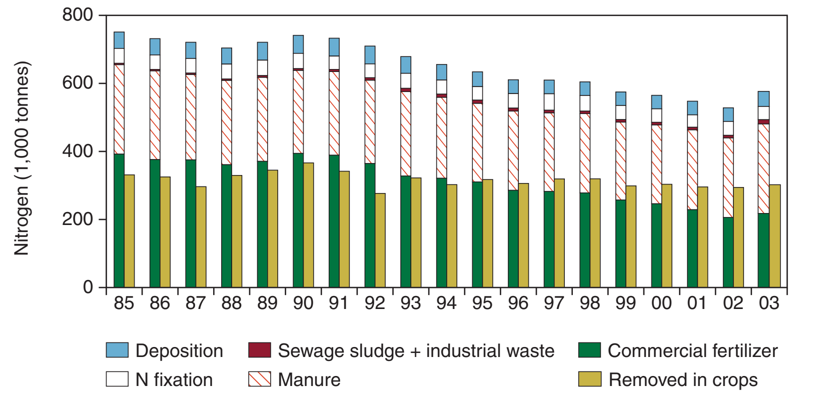


Figure 4.1 Field balance for applied nitrogen and nitrogen removed in the crops for all agricultural land in Denmark over the period 1985–2003 (*Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 4.2

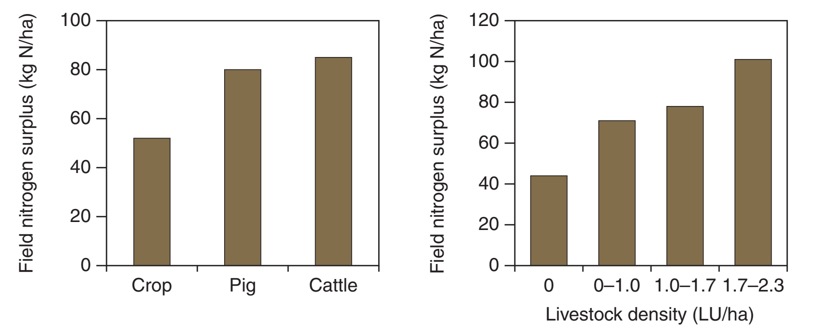


Figure 4.2 Field nitrogen surplus in the agricultural monitoring catchments in 2003 grouped according to type of holding and livestock density (*Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Table 4.1

Nitrogen (kg N/ha/yr)	1991 Whole country	1991 AMCs	2003 Whole country	2003 AMCs
Commercial fertilizer	140	121	74	73
Manure + sewage sludge	91	110	91	92
N fixation	14	23	15	14
N deposition	19	19	15	15
Total input	264	273	195	194
N removed in crops	123	132	102	122
N surplus	141	140	93	72

Table 4.1 Comparison of nitrogen input to cultivated land and nitrogen removed in the crops in the agricultural monitoring catchments (AMCs) and for the country as a whole in 1991 and 2003 (*Grant et al., 2004*).

Trend in nitrate concentration

In the agricultural catchment monitoring programme the nitrogen concentration is measured in the root zone at 18 field stations in three clayey soil catchments and at 14 field stations in two sandy soil catchments. There is considerable annual variation depending on the climatic conditions.

The trend in nitrate concentration has been determined for monitoring stations in sandy soil catchments and clayey soil catchments, respectively. With both types of catchment, a significant decrease (95% probability) was detected in the flow-weighted nitrate concentration in the soil water (Figure 4.4). The decrease was 0.7 mg N/l in the clayey soils and 1.4 mg N/l in the sandy soils. Smoothing the curve over the whole 13-year monitoring period yields a 38% decrease in the clayey soil catchments and a 50% decrease in the sandy soil catchments. The spread is considerable, however. With 95% probability the reduction in leaching lies between 24% and 50% for the clayey soils and between 40% and 66% for the sandy soils.

During the whole period the root zone nitrate concentration has exceeded the EU limit value for drinking water (11.3 mg N/l corresponding to 50 mg nitrate/l). The concentration is approaching this limit value, though.

Due to turnover of nitrate in the soil the concentration in the upper groundwater is lower. The concentration in the upper groundwater of the clayey soils has been below the limit value for drinking water during the whole period, while that of the sandy soils has been at the same level as the limit value since 1999/00 (Figure 4.4).

The nitrate concentration in the upper groundwater has decreased in the sandy soils, whereas no marked changes have been detected in the clayey soils. Variations in root zone nitrate concentration are accompanied by corresponding variations in the upper groundwater, except that these are delayed by approx. one year and are more smoothed out in the groundwater.

AQUATIC ENVIRONMENT 2004 – Figure 4.4

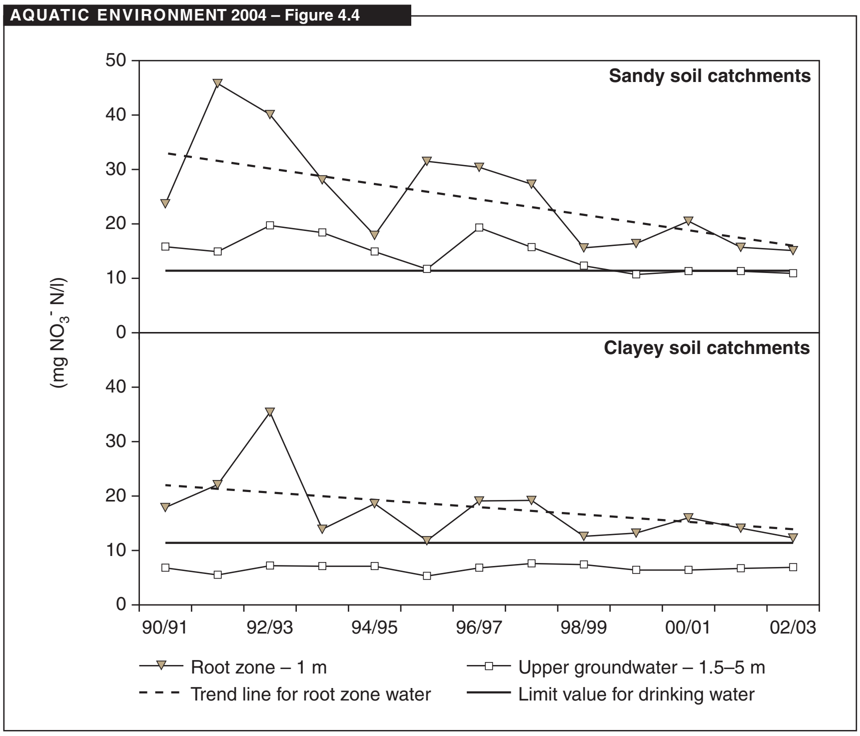


Figure 4.4 Trend in measured nitrate concentrations in the root zone water and upper groundwater in three clayey soil catchments and two sandy soil catchments over the period 1990/91–2002/03 (*Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 4.3

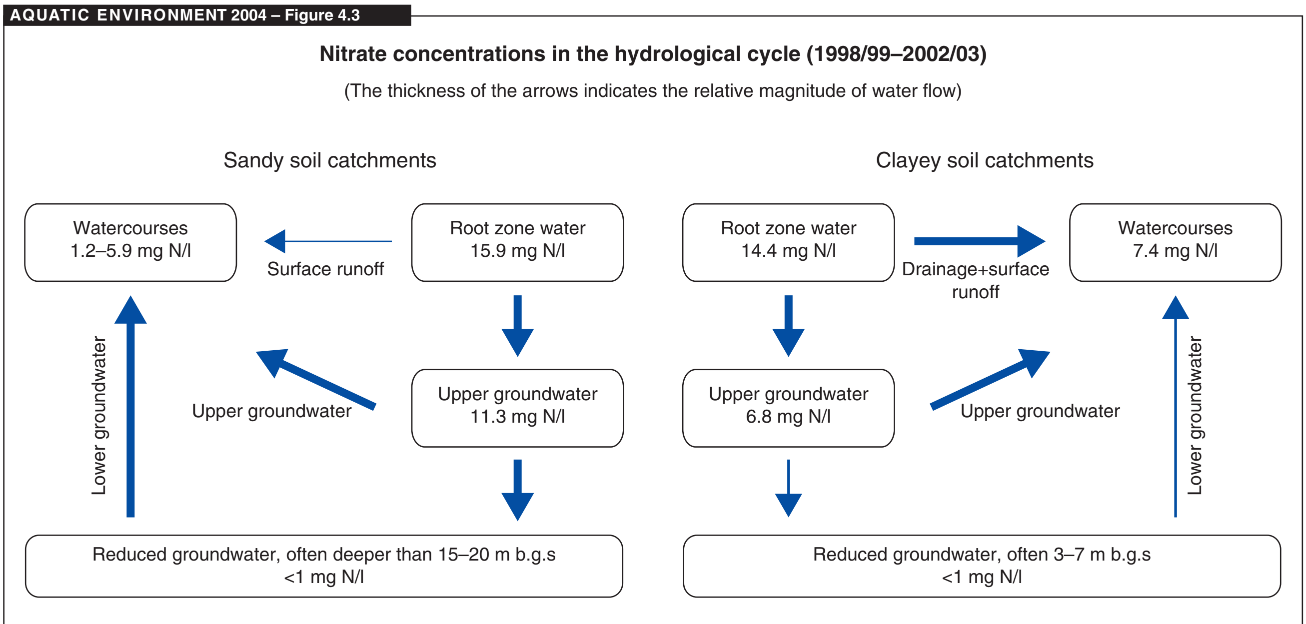


Figure 4.3 Mean measured nitrate concentrations in root zone water under the fields in the agricultural monitoring catchments (1 m b.g.s.), the upper groundwater (1.5–5 m b.g.s.) and in watercourses for three clayey soil catchments and two sandy soil catchments for the period 1998/99–2002/03 (*Grant et al., 2004*).

Model calculations of changes in nitrate leaching

The model calculations of leaching from the root zone in the agricultural monitoring catchments reveal a 52% decrease since 1990 in the sandy soils (Nordjylland and Sønderjylland Counties) and a 42% decrease in the clayey soils (Storstrøm, Funen, Aarhus and Vejle Counties) (Figure 4.5).

4.2 Phosphorus

Field balance for phosphorus

Nationwide consumption of phosphorus in commercial fertilizer has decreased from approx. 41,000 tonnes in 1990 to approx. 14,000 tonnes in 2003 (from approx. 15 kg P/ha/yr to 5 kg P/ha/yr), while inputs of phosphorus in the form of manure and sewage sludge have remained roughly unchanged. The field balance, i.e. the difference between the amount of fertilizer applied and that removed in the crops (the field surplus), has been decreasing over the period and was approx. 24,500 tonnes P in 2003 (Figure 4.6), corresponding to a mean value of 9 kg P/ha/yr for cultivated land as a whole.

This surplus and accumulation of phosphorus takes place on the livestock holdings. The surplus is greater on pig holdings than on cattle holdings, and increases with increasing livestock density (Figure 4.7). On crop holdings, less phosphorus is generally applied than is removed in the crops. On these holdings the phosphorus content of the soil thus decreases, in the long term thereby reducing the risk of phosphorus leaching.

Action Plan on the Aquatic Environment III

One of the targets stipulated in Action Plan on the Aquatic Environment III is that the total phosphorus surplus should be reduced by 50% before 2015 relative to the surplus in 2001, in part through levies on phosphate in livestock feed and in part through improved utilization of the phosphorus content of the feed.

This target is based on the total phosphorus surplus for Danish agriculture, 32,900 tonnes in 2003, which is different from the field balance shown in Figure 4.6. The Action Plan target will entail a halving of the rate at which phosphorus continues to accumulate on cultivated land.

Phosphorus content of the water under the fields

The loss of phosphorus from the soil to the groundwater or watercourses is small compared with the phosphorus content of the soil. The loss is also small compared with the amount applied as fertilizer because phosphate binds to soil particles under oxidizing conditions, i.e. when there is oxygen or nitrate in the soil water.

When the phosphorus binding capacity of the soil is almost used up the phosphorus content of the soil water will increase, as will leaching from the soil. Thus at a monitoring station in Storstrøm County the soil water

AQUATIC ENVIRONMENT 2004 – Figure 4.5

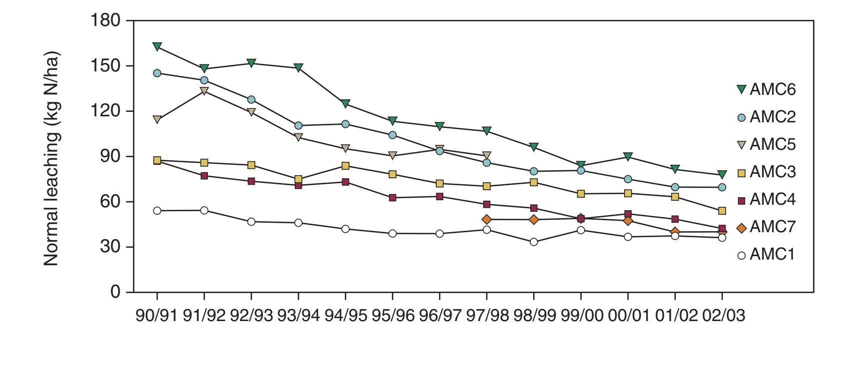


Figure 4.5 Modelled leaching of nitrate at average climatic conditions for the seven agricultural monitoring catchments (AMCs) over the period 1990/1991–2002/2003 (*Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 4.6

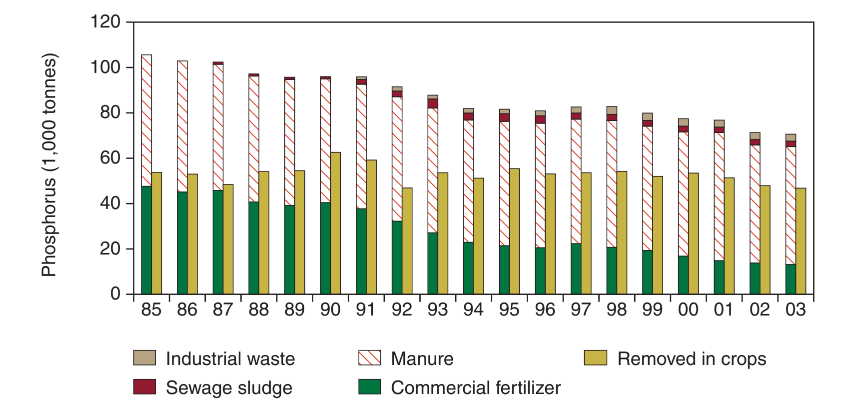


Figure 4.6 Field balance for applied phosphorus and phosphorus removed in the crops for all agricultural land in Denmark over the period 1985–2003 (*Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 4.7

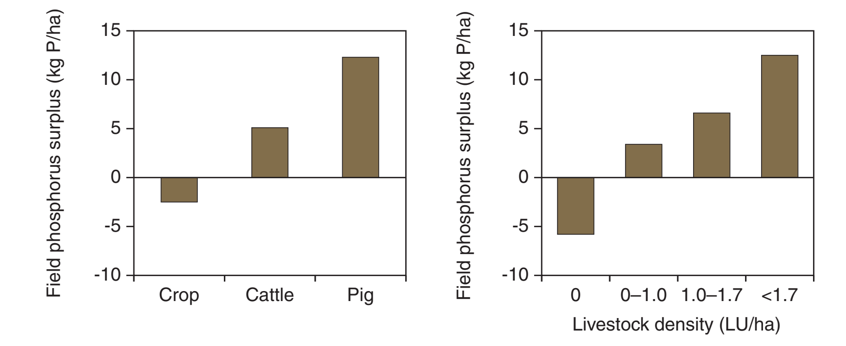


Figure 4.7 Field phosphorus surplus in the agricultural monitoring catchments in 2003 grouped according to type of holding and livestock density (*Grant et al., 2004*).

phosphorus concentration has been constantly high, probably due to a high soil phosphorus content. The phosphorus concentration can also be very high (0.1–0.5 mg P/l) in reduced (anoxic and nitrate-free) groundwater flowing to watercourses. The great binding capacity of the soil for phosphorus gives a buffering effect whereby large amounts of phosphorus can accumulate before major changes occur in the soil water phosphorus concentration. Changes due to changes in the level of phosphorus input will therefore normally occur after a decades-long delay. Thus no general changes have been detected in the phosphorus content of the soil since 1989.

The concentration of dissolved phosphorus in the water flowing from the root zone is generally lower than approx. 0.025 mg/l (*Grant et al., 2004*). However, there are a few fields in which the phosphorus concentration in the water has been 0.1–0.5 mg P/l, probably because the phosphorus binding capacity of the soil was low, or because the phosphorus content of the soil has been very high.

The phosphorus concentration in drainage water and surface runoff from the fields is higher because in addition to dissolved phosphorus the water also contains phosphorus bound to soil particles.

AQUATIC ENVIRONMENT 2004 – Table 4.2

AGRICULTURAL MONITORING CATCHMENTS	Phosphorus concentration (mg/l) 1989–2002	Phosphorus concentration (mg/l) 2002/2003	Phosphorus transport (kg/ha/yr) 1989–2002	Phosphorus transport (kg/ha/yr) 2002/2003
Højvads Rende (clayey)	0.111	0.117	0.19	0.19
Lillebæk (clayey)	0.192	0.162	0.55	0.28
Horndrup Bæk (clayey)	0.130	0.071	0.42	0.22
Odderbæk (sandy)	0.126	0.096	0.29	0.21
Bolbro Bæk (sandy)	0.081	0.061	0.41	0.35

Table 4.2 Flow-weighted mean concentrations of total phosphorus in watercourses draining agricultural monitoring catchments shown as the mean for the period 1989–2002 and the value for the year 2002/2003. Total phosphorus transport out of the catchments via the watercourses is shown for the same periods (data from *Grant et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 4.8

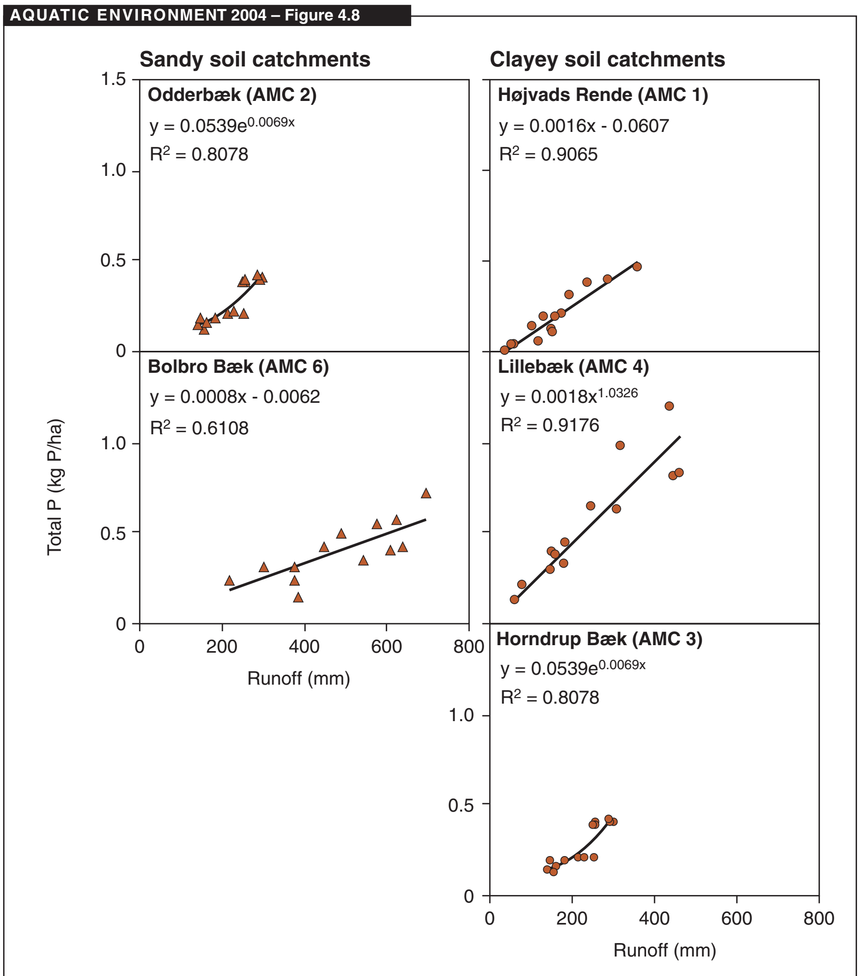


Figure 4.8 Correlation between annual phosphorus loss from agricultural land and freshwater runoff for the period 1989/90–2002/03 for the five agricultural monitoring catchments (AMCs). Each point represents one year's measurements (*Grant et al., 2004*).

Phosphorus loss to watercourses

The phosphorus concentration in watercourses is generally highest in clayey soil catchments (Table 4.2). This is due to the fact that the proportion of near-surface runoff is greatest here and that the water therefore contains more soil particles. Moreover, the proportion of wastewater from sparsely built-up areas that reaches the watercourses is greater in clayey soil areas because the possibilities for it to soak away are poorer.

The annual phosphorus transport via watercourses is highly dependent on the level of precipitation and freshwater runoff during the individual years. When runoff from the fields increases during high precipitation, the total phosphorus content of the runoff can increase if soil particles are washed away with the water. Figure 4.8 shows the relationship between total phosphorus loss and freshwater runoff each year for the five agricultural monitoring catchments.

From Figure 4.8 it is apparent that phosphorus transport via the watercourses in these five agricultural catchments is roughly proportional to freshwater runoff in the watercourses, but that the transport varies markedly from catchment to catchment.

5 Atmospheric inputs of nutrients

The input of nitrogen via the atmosphere plays an important role for total nitrogen loading of the Danish marine waters and landmass. One of the main aims of the atmospheric monitoring part of NOVA-2003 is therefore to determine the annual deposition of nitrogen on the aquatic environment and landmass. In contrast, the input of phosphorus from the atmosphere is normally of minor importance.

5.1 Deposition of nitrogen

Specific goals have not been set in Denmark for the magnitude of nitrogen deposition, nor have specific reduction targets been set. Pursuant to the Gothenburg Protocol, Denmark has adopted the goal of reducing nitrogen emissions to the atmosphere by 60% for nitrogen dioxides and by 43% for ammonia over the period 1990–2010. Overall, the Gothenburg Protocol will reduce European emissions of nitrogen dioxides by 41% and of ammonia by 17% (*Ellermann et al., 2004*).

Measurements in 2003

Model calculations based on measurements made in 2003 at the six main Danish stations (Figure 5.1) show that the annual deposition of nitrogen amounted to 12–24 kg N/ha on the landmass and 7–17 kg N/ha on the marine waters (Figure 5.2 and 5.3). This is roughly the same level as in 2002. The lowest deposition measured was at the Anholt station, which is located in the Kattegat far from major sources of nitrogen. The measurements at the Anholt station provide a good indication of nitrogen deposition on the Danish inner marine waters.

Deposition is higher on land than on water bodies in the same area because the vegetation traps the nitrogen compounds in the air, and because precipitation is greatest on land.

Deposition was highest at the Lindet and Tange stations, which are located in areas with high levels of ammonia volatilization from livestock. At the same time, they are in the part of Denmark where precipitation is highest. This contributes to the high deposition. The deposition measured at the Frederiksborg station is considerably below that at the Tange and Lindet stations due to the lower livestock density in this area north of Copenhagen and the lower precipitation.

As a result of the low precipitation, wet deposition was low in 2003 compared with the mean for the period 1989–2003. However, the low wet deposition was counterbalanced by the high dry deposition due to the relatively high concentrations in the air.

Uncertainty in the determination of the annual nitrogen deposition is estimated to be 12–25% for deposition on the marine waters and 27–43% for deposition on the landmass.

Nitrogen input to marine waters via the air

Input via the atmosphere is calculated using an air pollution model (ACDEP) based on the magnitude and location of the sources of pollution in Europe, the meteorological conditions and chemical transformations of nitrogen in the atmosphere (*Ellermann et al., 2004*). The uncertainty in the calculations is considered to be up to 30% for the open marine waters and up to 50% for the coastal waters.

Total deposition of nitrogen on Danish marine waters in 2003 is calculated to be 124,000 tonnes N. Given a total sea area of 105,000 km^2, this corre-

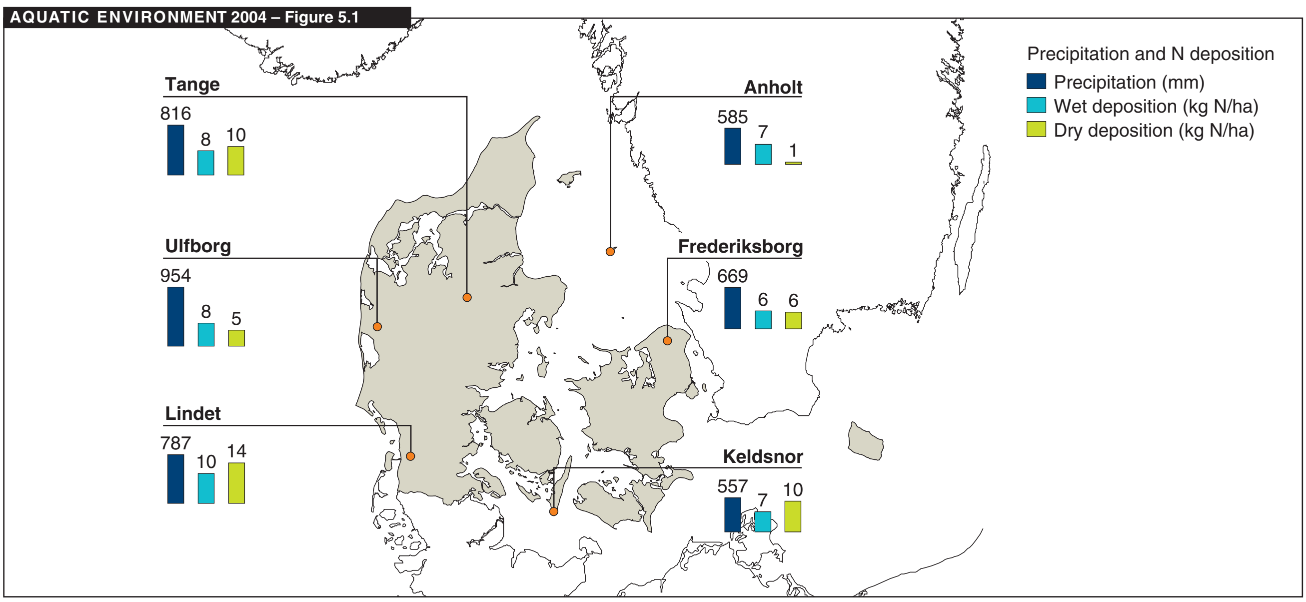


Figure 5.1 Nitrogen deposition (kg N/ha) and precipitation (mm) at the six monitoring stations in 2003. The values for Anholt are for deposition on water, while the values for the other stations are for deposition on an average land surface (approx. 10-cm high vegetation) (*Ellermann et al., 2004*).

sponds to a mean deposition of 12 kg N/ha. The deposition of nitrogen in 2002 was calculated to be 107,000 tonnes N. The difference lies within the uncertainty of the calculations.

The deposition varies by a factor of two between the various marine waters and is greatest in coastal areas, where the distance to the sources is short. The calculated deposition was thus highest for parts of Limfjorden (17 kg N/ha) and lowest in the Baltic Sea north of Bornholm (7 kg N/ha). The amount of precipitation is also a significant determinant of the amount of deposition. As a consequence, the deposition is generally higher in the western part (where it rains considerably more) than in the eastern part.

The distribution of nitrogen deposition between dry deposition and wet deposition is shown in Table 5.1. Deposition on marine waters is mainly accounted for by wet deposition, whereas the difference between the amounts of wet and dry deposition is smaller for land areas.

AQUATIC ENVIRONMENT 2004 – Table 5.1

ATMOSPHERIC N DEPOSITION	Area (km²)	Dry deposition (1,000 tonnes N/yr)	Wet deposition (1,000 tonnes N/yr)	Total (1,000 tonnes N/yr)	Total (kg N/ha/ yr)
Danish marine waters	105,372	31	93	124	12
Danish landmass	43,312	47	85	85	20

Table 5.1 Calculated total nitrogen deposition on Danish marine waters (incl. the Swedish parts of the Kattegat and the Øresund) and landmass in 2003 (*Ellermann et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 5.2

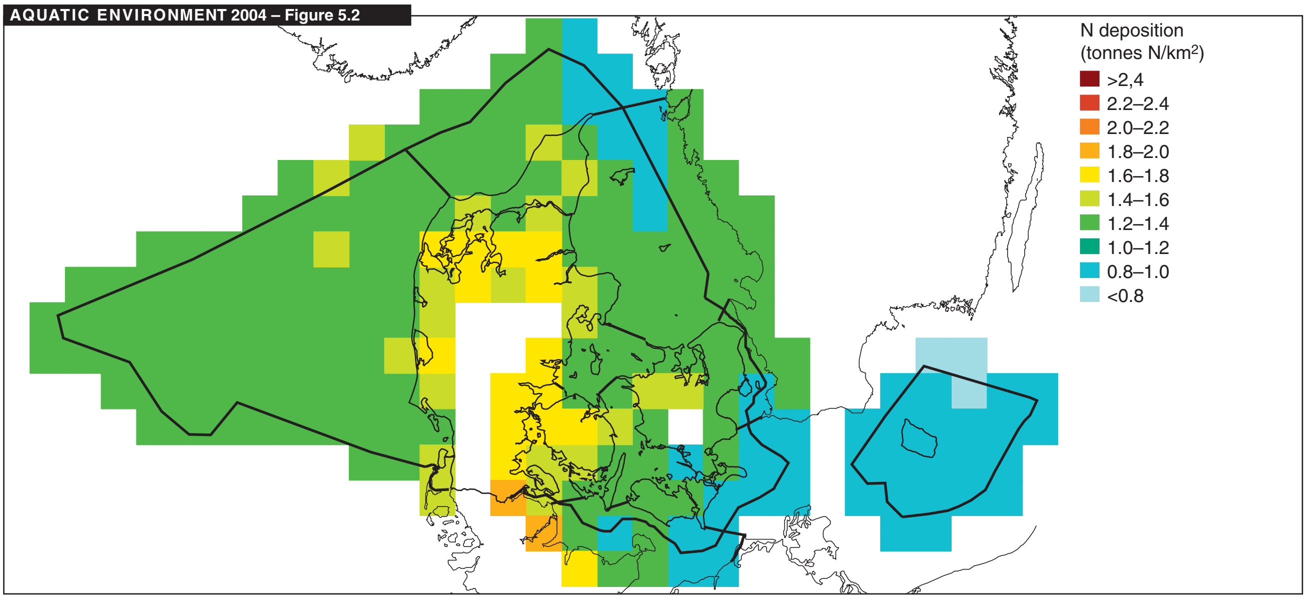


Figure 5.2 Calculated total deposition of nitrogen compounds on Danish marine waters in 2003. The values only encompass deposition on water surfaces within the quadrants and are given in tonnes N/km² (multiplying these values by 10 yields the deposition in kg N/ha). The quadrants are 30 km x 30 km (*Ellermann et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 5.3

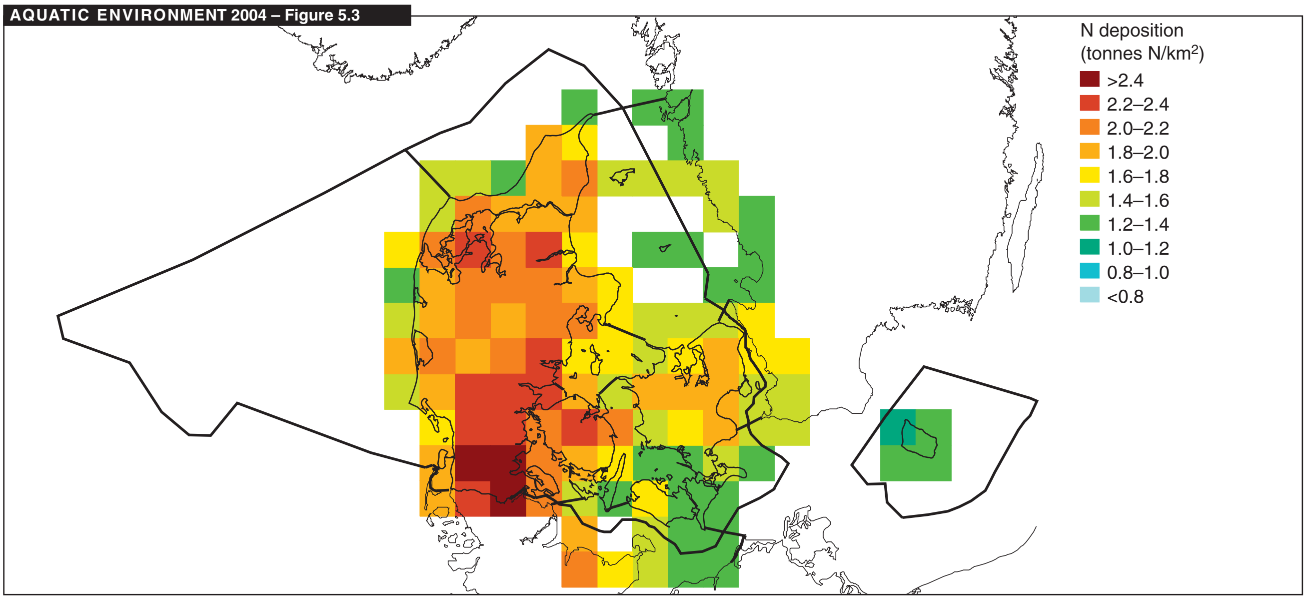


Figure 5.3 Calculated total deposition of nitrogen compounds on the Danish landmass in 2003. The values only encompass deposition on land surfaces within the quadrants and are given in tonnes N/km² (multiplying these values by 10 yields the deposition in kg N/ha). The quadrants are 30 km x 30 km. The values are calculated for deposition on an average land surface (approx. 10-cm high vegetation) (*Ellermann et al., 2004*).

Nitrogen input to the landmass via the air

Deposition of nitrogen on the Danish landmass in 2003 is calculated to be 85,000 tonnes N, which corresponds to the figure for 2002 (80,000 tonnes N).

The deposition varies between 12 kg N/ha and 24 kg N/ha (Figure 5.3). The reason for the great geographic variation is mainly that the magnitude of deposition depends on the local agricultural activity, because ammonia is deposited close to the source. At the very local scale the variation will be considerably greater than that calculated as a mean for each of the 30×30 km quadrants used in the model, either due to local sources (livestock holdings) and/or because trees will capture ammonia from the air. Deposition is high in Jutland, where livestock production is high and where precipitation is greatest, and lowest on Bornholm, where major sources are far away and where precipitation is low.

The mean deposition, which is 20 kg N/ha/yr, is on par with or above the critical load for many of the vulnerable Danish habitat types, for example raised bogs (5–10 kg N/ha/yr) and heathland (10–15 kg N/ha).

Sources of nitrogen deposition

The nitrogen deposited on the Danish landmass and marine waters derives from a large number of Danish and foreign sources. In order to be able to assess the effect of emission reductions it is necessary to quantify the various Danish and foreign sources of the nitrogen deposited on Denmark.

Using modelling it is possible to estimate the proportion of the deposition on Denmark that derives from Danish and foreign sources, respectively. It is also possible to differentiate between deposition attributable to the emission of nitrogen oxides from combustion processes (e.g. transport, power stations, incineration plants and industrial production) and emission of ammonia from agriculture.

The calculations show that the deposition on both the Danish marine waters and the landmass derives approximately equally from combustion processes and agricultural production.

Sources of the nitrogen deposited on marine waters

By far the majority of the nitrogen deposited on Danish marine waters derives from foreign sources (Figure 5.4). On average, the Danish share of the deposition on the Danish open marine waters is only approx. 12%, being greatest in the Kattegat (22%) and least in the North Sea (7%), which is in accordance with the fact that the wind direction is most frequently from the south and the west. The proportion deriving from Denmark can be considerably greater for closed fjords, coves and bays due to the proximity to Danish sources. An example is Limfjorden, where around 36% derives from Danish sources. Figure 5.4 also shows that the Danish share of the deposition mainly derives from agricultural production and that the local differences in the Danish share are largely attributable to differences in the contribution from agriculture.

Sources of the nitrogen deposited on the landmass

The Danish share of the mean deposition on Jutland, Funen, Zealand and Bornholm (Figure 5.5) is greater than that for deposition on Danish marine waters. The primary reason for this is the greater deposition of ammonia from local farms. The Danish share of deposition is greatest in Jutland (38%) due to the high level of livestock production, and least on Bornholm (11%).

Trend in nitrogen deposition

The trend in deposition calculated as the mean deposition at NERI's main monitoring stations is shown in Figure 5.6. The results reveal an approx. 21% decrease in nitrogen deposition on both the Danish marine waters and the Danish landmass. These results are considered to describe the general trend for Denmark as a whole.

AQUATIC ENVIRONMENT 2004 – Figure 5.4

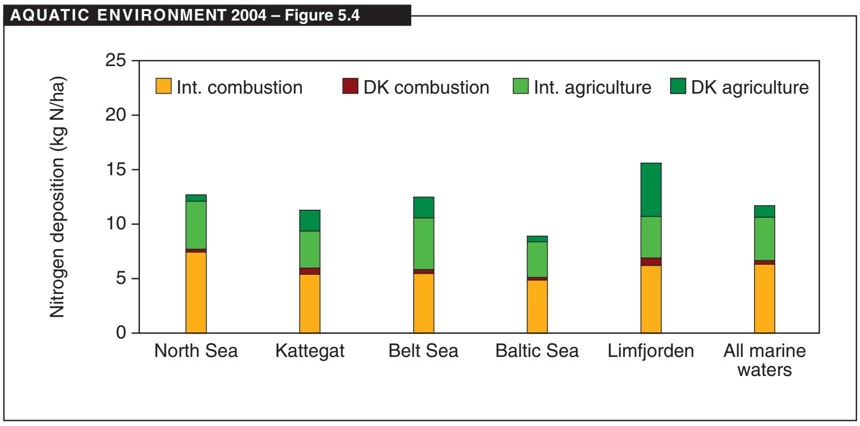


Figure 5.4 Nitrogen deposition on selected Danish marine waters in 2003 apportioned by Danish and international sources and subdivided by emissions from combustion processes and agricultural production (*Ellermann et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 5.5

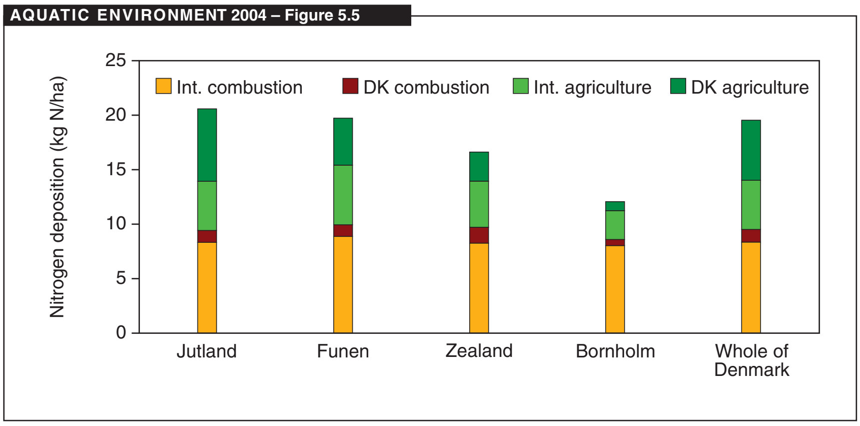


Figure 5.5 Mean nitrogen deposition on Jutland, Funen, Zealand, Bornholm and Denmark as a whole in 2003 apportioned by Danish and international sources and subdivided by emissions from combustion processes and agricultural production (*Ellermann et al., 2004*).

5.2 Deposition of phosphorus

The total deposition of phosphorus consists of the sum of dry deposition of particle-bound phosphorus and wet deposition of phosphorus in raindrops, snow, etc. Total deposition of phosphorus on the inner Danish marine waters and the landmass is calculated to be approx. 0.04 kg P/ha (*Ellermann et al., 2003*). Deposition on the Danish inner marine waters (total area 31,500 km^2) in 2003 can therefore be estimated to be approx. 130 tonnes P. The corresponding estimate for deposition on the Danish landmass (43,000 km^2) is approx. 170 tonnes P.

In NERI's assessment, atmospheric deposition of phosphorus has remained unchanged over the period 1989–2003.

AQUATIC ENVIRONMENT 2004 – Figure 5.6

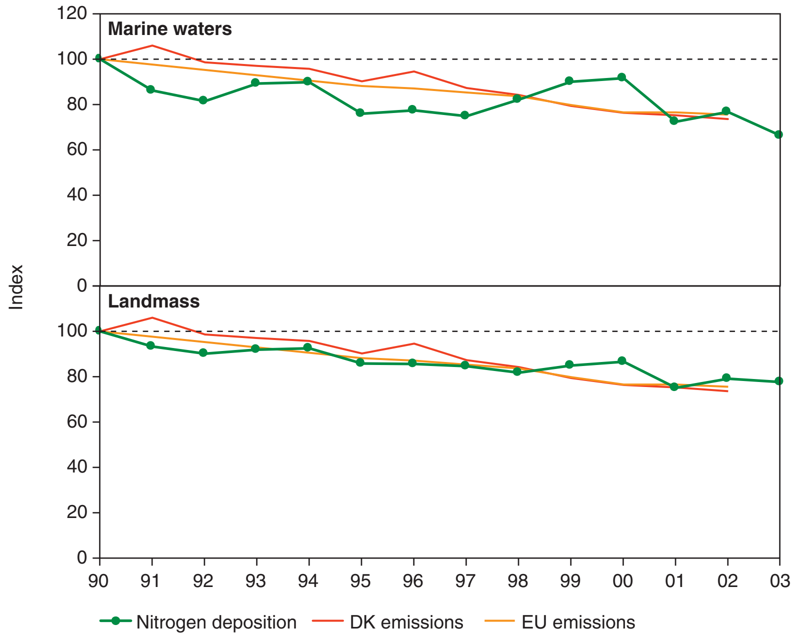


Figure 5.6 Trends in total nitrogen deposition compared with atmospheric emissions of nitrogen in Denmark and in the rest of the EU. The upper panel shows the trend for deposition on the inner Danish marine waters. The lower panel shows the trend for deposition on the Danish landmass. All values are indexed to 100 in 1990 (*Ellermann et al., 2004*).

6 Groundwater

The problem of groundwater pollution is largely due to a raised nitrate concentration resulting from cultivation of the land. This can cause health problems with the drinking water, and the nitrate in the groundwater can, when it flows into the surface waters, contribute to eutrophication of lakes and marine waters. In addition, the groundwater can contain pesticides and other hazardous substances that can render it unfit for use as drinking water. These substances are described in Chapters 10, 11 and 12.

Groundwater monitoring programme

The programme encompasses 70 groundwater monitoring sites reasonably evenly distributed throughout the country. Each contains approx. 17 monitoring filters (Figure 1.1).

The groundwater monitoring is carried out each year at a permanent network of approx. 1,050 filters. In addition, the programme includes 112 filters for monitoring of the main chemical elements in the Rabis Bæk area at Karup and 77 filters in four so-called redox wells established in 1998–1999.

The groundwater monitoring programme also includes approx. 85 filters in the groundwater at the five agricultural monitoring catchments, where among other things the quality of the newly formed groundwater is monitored 1.5–5 m below ground surface.

Finally, the programme incorporates the analysis results of the waterworks' control of the water abstracted from their wells for the water supply (*GEUS, 2004*).

6.1 The groundwater resource

The magnitude of groundwater recharge is mainly determined by the amount of winter precipitation. The groundwater level was very low after the very dry winters 1995–1997, but rose during the subsequent wet years. Whereas 2002 was an unusually wet year, winter 2002/2003 was rather dry, and the winter precipitation in 2003/2004 was close to normal. At the end of winter 2003/2004 the groundwater level was close to the seasonal normal.

Groundwater abstraction

The total amount of groundwater abstracted in 2003 was 634 million m^3. In addition, surface water abstraction totalled 11 million m^3, excluding that abstracted by freshwater fish farms. In comparison, freshwater runoff to the sea amounted to 10,660 million m^3. Of the total amount of water abstracted, 64% was abstracted by the waterworks for the water supply, while 24% was accounted for by field irrigation, market gardens and freshwater fish farms.

On Zealand, where the population density is high and the precipitation surplus is low, a large proportion of the total water resource is used for the water supply.

In Ringkjøbing and Ribe Counties in particular, large amounts of groundwater are abstracted for field irrigation (44% and 42% of all the groundwater abstracted in 2003, respectively). Water consumption for field irrigation was low in 2002 and 2003 due to the relatively wet summer months and hence the lower water requirements. In Nordjylland County, 27% of the abstracted groundwater was used for fish farming in 2003.

Trend in water abstraction

Since the inception of the monitoring programme in 1989, total groundwater abstraction has decreased by 39% from approx. 1,000 million m^3/yr to 6–700 million m^3/yr (Figure 6.1).

The decrease in water abstraction is due to a 37% decrease in abstraction by waterworks from approx. 600 million m^3/yr around 1990 to approx. 400 million m^3/yr in 2000, at which time the decrease in water consumption stagnated.

Water consumption for field irrigation and market gardens has been considerably lower over the past six years than during the preceding period 1989–1997. This is due to the greater and more seasonally appropriate precipitation during May–June in recent years.

AQUATIC ENVIRONMENT 2004 – Figure 6.1

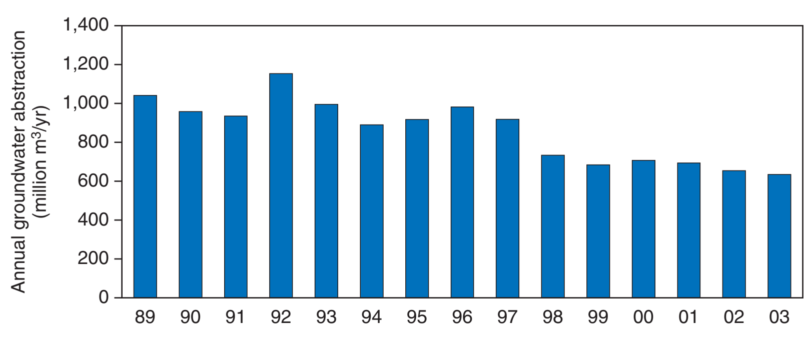


Figure 6.1 Total groundwater abstraction in Denmark over the period 1989–2003 (*GEUS, 2004*).

6.2 Nitrate in groundwater

The distribution of nitrate concentration in the groundwater monitoring sites and waterworks wells in 2003 is shown in Figure 6.2. The groundwater nitrate concentration exceeds the limit value for drinking water (50 mg/l) in 16% of the filters at the groundwater monitoring sites, while the corresponding figure for the waterworks wells is only approx. 1%. The majority of the waterworks wells (75%) and many of the filters in the groundwater monitoring sites (40%) contain less than 1 mg nitrate/l. The distribution of nitrate concentration has remained largely unchanged since the monitoring programme began.

AQUATIC ENVIRONMENT 2004 – Figure 6.2

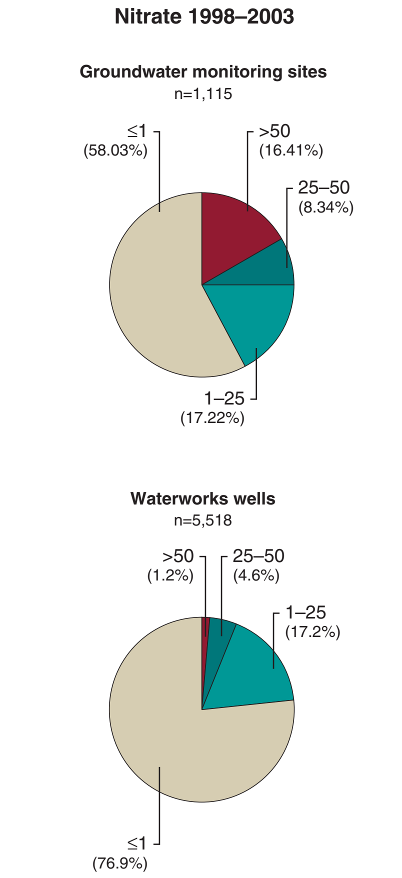


Figure 6.2 Distribution of nitrate concentration in groundwater at the groundwater monitoring sites and in waterworks wells for the period 1998–2003 (*GEUS, 2004*).

Nitrate concentration depends on depth

The majority of samples containing nitrate derive from filters located less than 30–50 m b.g.s. (Figure 6.3). Not unexpectedly, the nitrate concentration is highest in filters located in the upper 10 m, where it exceeds 50 mg/l in more than 15% of the filters. The decrease in nitrate concentration with increasing depth is not solely due to the fact that the nitrate concentration in the old groundwater found at great depths was lower when it was formed many decades ago, but is also due to the reduction in nitrate content (denitrification) that takes place when nitrate-containing water penetrates down into the reducing (anoxic) soil layers.

The nitrate concentration depends both on input and on turnover in the groundwater

The distribution of nitrate concentration with depth (Figure 6.3) correlates with the geochemical subdivision of the groundwater into four redox zones, where the uppermost zone with a high redox potential – the oxic zone – has a high oxygen content, and the nitrate content can be high due to leaching from the root zone.

In the next zone – the nitrate zone – the oxygen content is low because it has been utilized, among other reasons to degrade organic matter in the soil. Reduction of nitrate takes place in this zone, but the nitrate content of the water remains considerable.

Beneath the nitrate zone is the iron and sulphate zone. This contains iron and sulphate but no nitrate and oxygen.

The lowermost zone is the strongly reduced sulphide-containing/sulphate-reducing zone – the methane zone – the redox potential of which is very low. In the two lower zones the groundwater will often also contain high concentrations of phosphorus.

Trend in nitrate content

A very large proportion of the monitored groundwater was formed prior to adoption of the Action Plan on the Aquatic Environment. An effect of the measures implemented as part of the Action Plan are not yet expected to be measurable in this groundwater.

The mean nitrate concentration in the youngest groundwater has generally decreased in both the agricultural monitoring catchments and the groundwater monitoring sites (*Grant et al., 2004*, and *GEUS, 2004*).

Geographic distribution of nitrate in the groundwater

As in previous years, the proportion of filters revealed by the waterworks well control as having a nitrate concentration exceeding 25 mg/l is highest in Nordjylland, Viborg and Aarhus Counties – especially in the so-called "Nitrate belt" stretching from the northwestern part of Aarhus County into Viborg County (Figure 6.4). This is due to the combination of high nitrate loading and unfavourable geological conditions (low nitrate reduction capacity) pertaining in this area.

The groundwater that is abstracted for the drinking water supply in poorly protected areas such as on Mors,

AQUATIC ENVIRONMENT 2004 – Figure 6.3

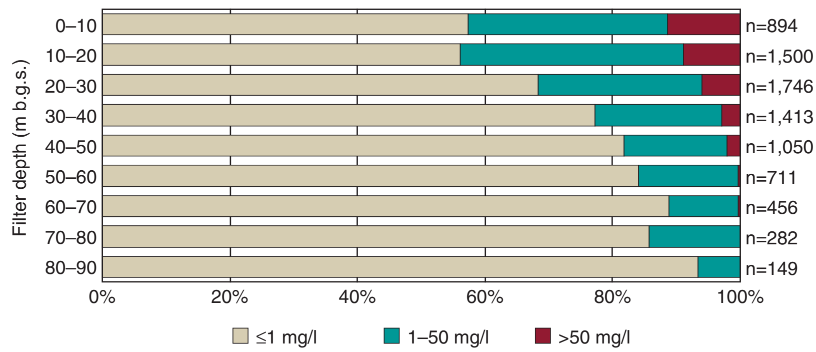


Figure 6.3 Distribution of nitrate concentration according to filter depth for agricultural monitoring catchments, groundwater monitoring sites and waterworks wells, etc. for the period 1998–2003. The number of filters is indicated (*GEUS, 2004*).

near Aalborg, on Djursland, around Roskilde Fjord and on Bornholm also has a high nitrate content. Thus it is still in Jutland, where the sandiest soils are located, that the proportion of wells with a relatively high nitrate content is greatest. The data for the group "Other wells", which encompasses waterworks wells used for purposes other than water abstraction, e.g. measuring the water table and remedial pumping, are unevenly distributed as the majority of the information derives from Storstrøm, Sønderjylland, Ribe, Viborg and Nordjylland Counties. Many of these measurements are from shallow wells and therefore represent groundwater from close to the surface. These data derive from an investigation of small private water supply wells (*GEUS, 2004a*).

6.3 Phosphorus in groundwater

The phosphorus content of the groundwater depends on the geological conditions and especially on the so-called redox potential in the aquifer (see under nitrate).

The trend and distribution of total phosphorus in the four redox zones over the period 1998–2003 is shown for the data from the groundwater monitoring sites in Figure 6.5. In both the oxic and nitrate zones the concentration of dissolved total phosphorus is low and in nearly all filters is below

AQUATIC ENVIRONMENT 2004 – Figure 6.5

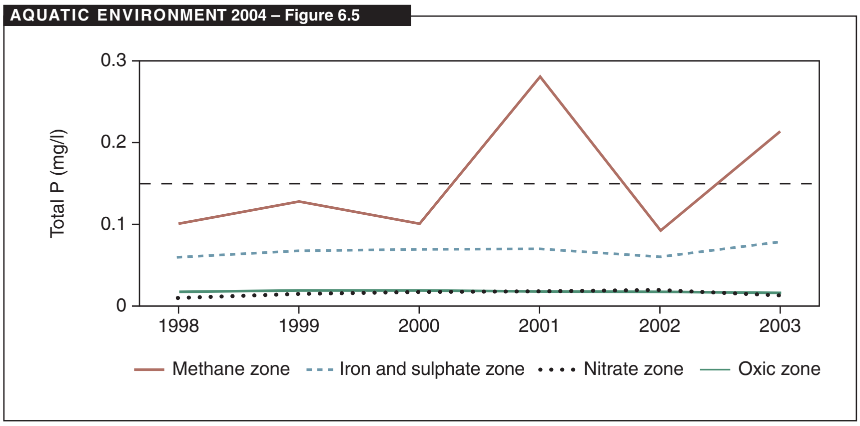


Figure 6.5 Groundwater concentration of dissolved total phosphorus in mg/l over the period 1998–2003. The curves represent the annual mean for the four redox zones at the groundwater monitoring sites. The limit value for phosphorus in drinking water (0.15 mg P/l) is indicated (*GEUS, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 6.4

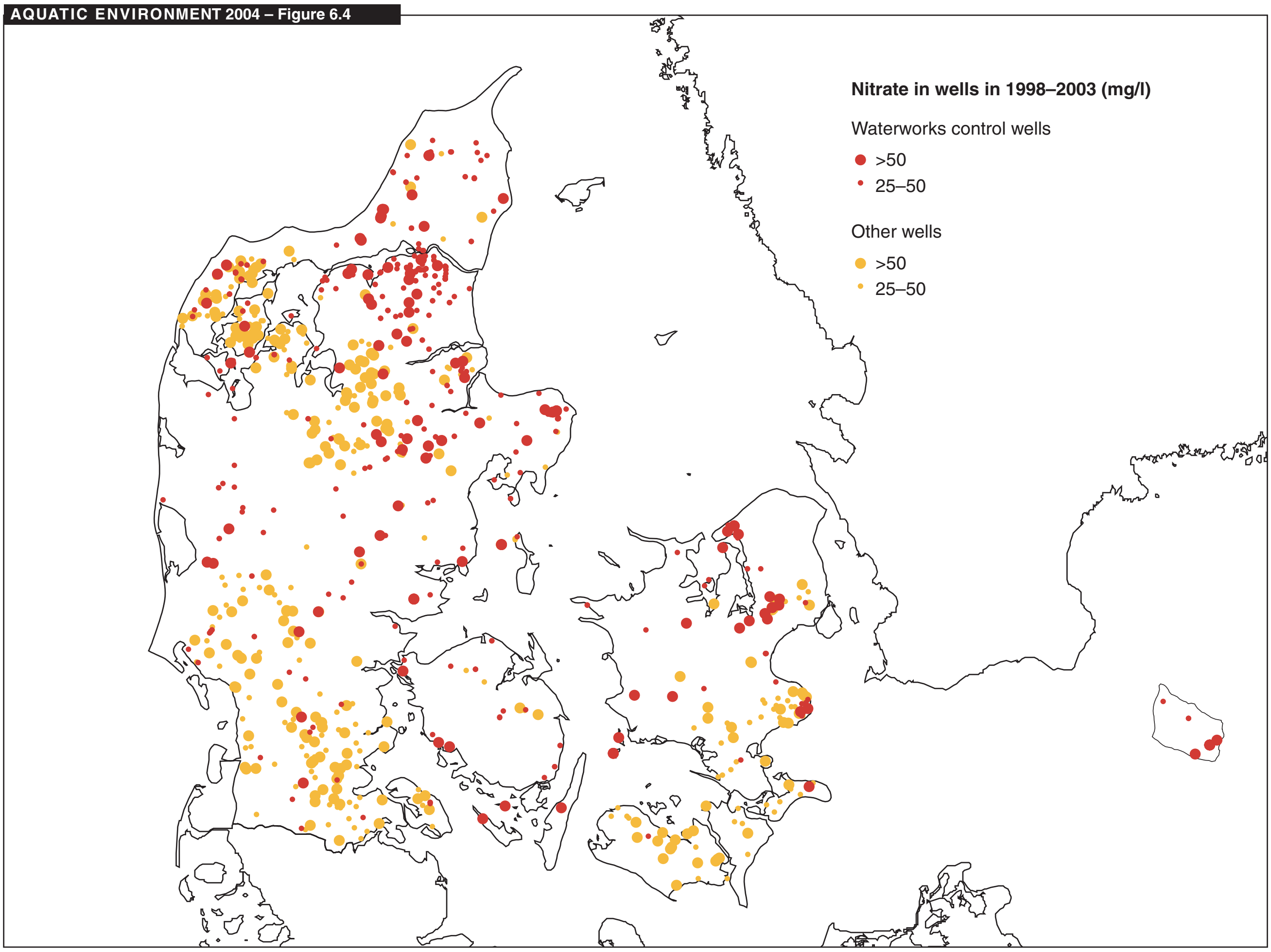


Figure 6.4 Waterworks control wells and "Other wells" with a nitrate concentration of 25–50 mg/l and >50 mg/l for the period 1998–2003. In the case of waterworks wells, these account for 6% of all the wells in use. Wells with a nitrate concentration of <25 mg/l are not shown (*GEUS, 2004*).

the limit value for drinking water (0.15 mg/l). Under these redox conditions phosphorus is bound to soil particles, for example as iron compounds. Moreover, the concentration has remained unchanged over the period. In the iron and sulphate zone the phosphorus concentration is higher – up to 0.1 mg/l on average, although values as high as 0.3 mg/l are not uncommon. In more than 75% of the filters, however, the concentration is below the limit value for drinking water. In the methane zone the concentration of dissolved phosphorus is often very high – a mean of approx. 0.2 mg/l, but with values of 0.4 mg/l not being uncommon. These high phosphorus concentrations are natural in origin and mainly occur in younger marine deposits.

Eutrophication of surface waters

A high groundwater phosphorus concentration is not a problem as regards the water supply as the phosphorus will normally be removed by treatment at the waterworks before the water reaches the consumers. In contrast, a phosphorus concentration exceeding approx. 0.05 mg/l could cause eutrophication of downstream lakes and fjords if the groundwater flows into surface water. If the groundwater concomitantly contains considerable amounts of iron, this will precipitate out phosphorus in the form of iron compounds, however, and thereby remove phosphorus from the water.

Geographic distribution of phosphorus in groundwater

In certain parts of the country the phosphorus concentration in the waterworks wells is relatively high. In approximately 20% of the filters for which data have been reported the concentration of dissolved phosphorus is more than 0.15 mg P/l. The high phosphorus concentrations relate to wells in which the water has been in contact with clayey marine deposits from the interglacial periods, such as in northern and southern Jutland and on Als, Ærø and Langeland, etc. (Figure 6.6). In areas with limestone deposits and lacking in these marine deposits such as in large parts of Zealand and on Lolland, Falster and Møn and in Djursland, Himmerland and Hanherred, there are only very few wells with a high phosphorus concentration.

In the private wells without water treatment the limit value for drinking water is exceeded in approx. 10%, probably due to input of contaminated surface water.

AQUATIC ENVIRONMENT 2004 – Figure 6.6

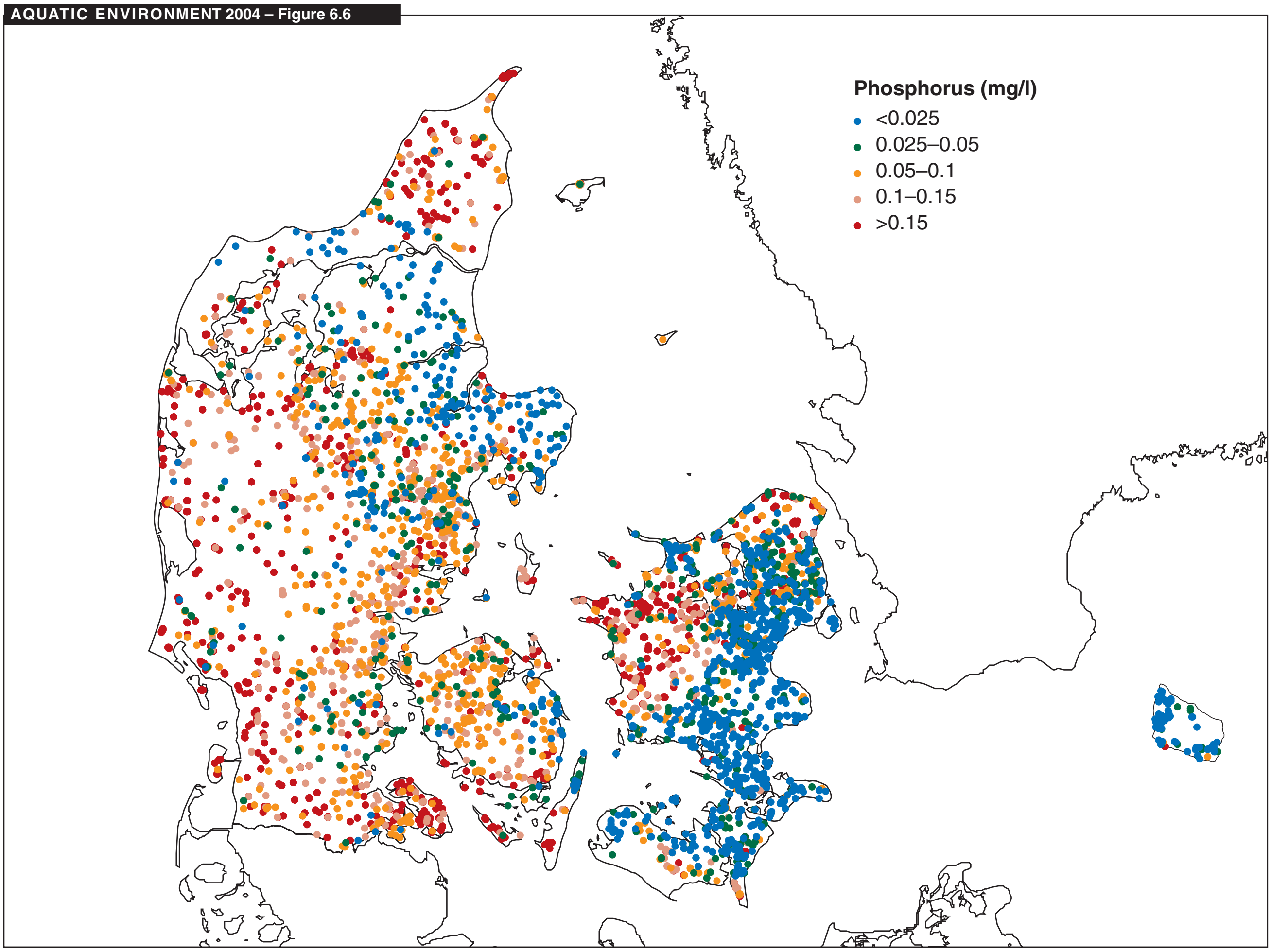


Figure 6.6 Total phosphorus concentration in waterworks wells for the period 1998–2003. Only data for the reduced groundwater, where the concentrations of both oxygen and nitrate are less than 1 mg/l, are shown (*GEUS, 2004*).

7 Lakes

The dominant pollution problem in Danish lakes is the elevated algal biomass in the lake water, which is mainly attributable to high phosphorus loading. Nitrogen loading is also of significance for the environmental state of some lakes. The most polluted lakes are those affected by wastewater. Due to wastewater treatment during recent decades, however, the main source of pollution is now leaching of phosphorus from cultivated land.

Due to phosphorus removal from the wastewater, phosphorus loading of the recipient lakes has decreased markedly, and improvements have been recorded regarding Secchi depth and algal biomass in 10–12 of the 27 freshwater lakes included in the monitoring programme. The improvements in lakes usually take place after a delay of decades, however, due to the phosphorus accumulated in the lake sediment.

7.1 Nutrient inputs to lakes

The size of the nutrient sources and of the total input of nutrients to the individual lakes depends entirely on the nature of each lake's catchment and the activities within it. Rough classification of the monitoring lakes according to catchment loading category is given in Table 7.1. The majority of the lakes have cultivated catchments, while fewer lakes receive urban wastewater. In Table 7.1, "Wastewater" encompasses wastewater inputs from both towns and from rural properties outside the sewerage catchment (sparsely built-up areas).

Source apportionment of phosphorus and nitrogen

Approximately half of the phosphorus input to the monitoring lakes in 2003 derived from diffuse loading, i.e. leaching from land within the catchments (Figure 7.1). This encompasses both the natural background leaching and the additional leaching resulting from cultivation of the land in the catchments. This share of the total input is less than in previous years because 2003 was a relatively dry year, which resulted in reduced diffuse loading.

The leached phosphorus is present in the runoff partly in dissolved form and, especially during periods of high runoff, partly in particulate form bound to the soil particles that are transported with the water.

It is difficult to apportion diffuse loading between natural background loading and the additional loading resulting from cultivation of the land. It is estimated that in the catchments of the watercourses monitored under NOVA-2003, leaching of phosphorus from cultivated land is approx. 2–3-fold greater than leaching from uncultivated countryside (*Bøgestrand (ed.), 2004*). This probably also applies to the catchments of the lakes monitored under NOVA-2003 (see Chapter 8, Table 8.3).

As regards nitrogen, diffuse loading is calculated to account for 72% of the total input to the lakes. This is around the same level as in previous years.

A considerable proportion of the phosphorus input to the lakes (29%) derives from sparsely built-up areas, this source accounting for more than all the other wastewater sources combined in that discharges from wastewater treatment plants, stormwater outfalls and freshwater fish farms combined only account for approx. 10% of the total. As regards nitrogen loading, these discharges are of no importance (Figure 7.1).

AQUATIC ENVIRONMENT 2004 – Table 7.1

CHARACTERISTICS OF LAKE CATCHMENTS 2003	No. of lakes
Wastewater >25% of P input	11
More than 50% cultivated	19
More than 50% paved	3
More than 50% woodland/ semi-natural	4

Table 7.1 Catchment loading category for the 31 monitoring lakes. Some of the lakes are encompassed by more than one of the catchment loading categories, while others are outside these categories (data from *Jensen et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 7.1

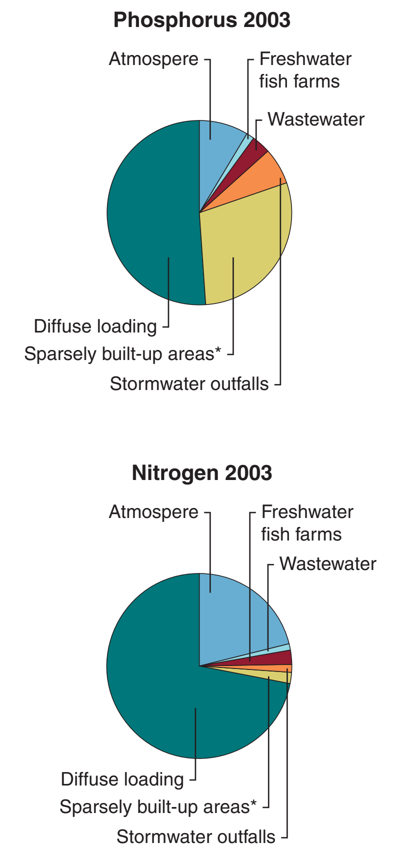


Figure 7.1 Source apportionment of phosphorus and nitrogen inputs to the monitoring lakes in 2003. The figures are based on the mean of the source apportionment for the individual lakes and hence cannot be compared with the absolute figures shown in Table 7.2.
* Wastewater from rural properties outside the sewerage catchment (*Jensen et al., 2004*).

Total inputs of phosphorus and nitrogen

The total annual inputs of phosphorus and nitrogen to the monitoring lakes are shown in Table 7.2 as means for the periods 1989–1995 and 1996–2002 and for 2003. Phosphorus input to the lakes had already been reduced considerably prior to 1989 because most wastewater treatment plants discharging into these lakes had previously been upgraded to include phosphorus removal, or discharge of the treated wastewater into the lakes had been stopped.

AQUATIC ENVIRONMENT 2004 – Table 7.2

P AND N SOURCES	Period	Phosphorus input (tonnes/yr)	Nitrogen input (tonnes/yr)
Total input	1989–95	3.98	163.2
	1996–02	2.07	99.5
	2003	1.55	55.3
Wastewater treatment plants	1989–95	1.80	14.7
	1996–02	0.37	5.8
	2003	0.22	4.4
Stormwater outfalls	1989–95	0.30	1.2
	1996–02	0.25	1.0
	2003	0.21	0.8
Sparsely built-up areas*	1989–95	0.64	2.1
	1996–02	0.45	2.0
	2003	0.46	2.0
Freshwater fish farms	1989–95	0.07	0.8
	1996–02	0.01	0.7
	2003	0.01	0.6
Diffuse loading	1989–95	1.08	136.9
	1996–02	1.01	93.6
	2003	0.66	44.8

Table 7.2 Phosphorus and nitrogen inputs to the monitoring lakes apportioned by source. Values are means for the periods 1989–1995 and 1996–2002 and for 2003.
* Wastewater from rural properties outside the sewerage catchment (*Jensen et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 7.2

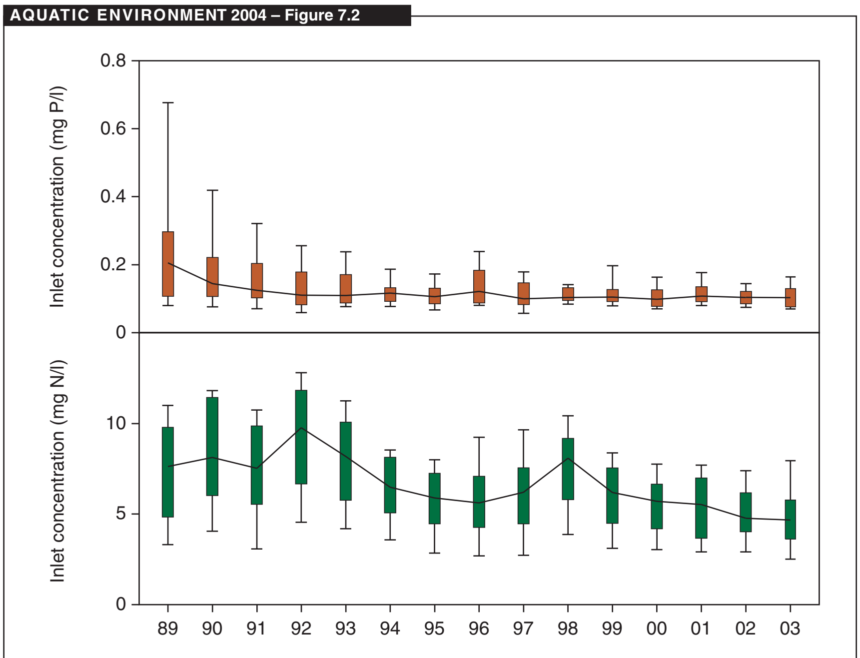


Figure 7.2 Phosphorus and nitrogen concentrations in the water running into the monitoring lakes over the period 1989–2003. The curves connect the median values for the individual years. The 10% and 25% percentiles are also shown (*Jensen et al., 2004*).

The figures in Table 7.2 show the marked decrease in phosphorus input from wastewater treatment plants. It is also calculated that diffuse nitrogen loading has decreased considerably, in part due to general reduction in leaching from cultivated land and in part to the low runoff in 2003. The calculated reduction (in 2003 approx. one third of the level in 1989–1995) is remarkably great relative to the measured general reduction in riverine transport of nitrogen, however (see Chapter 8).

P and N concentrations in the lake inlets

The trends in the phosphorus and nitrogen concentrations in the water flowing into the lakes differ markedly (Figure 7.2).

The phosphorus concentration in the inlet water has decreased considerably since 1989 in the lakes receiving wastewater, where the inlet concentrations were high. The median values for all the lakes as a whole have remained virtually unchanged during the period, however, because phosphorus input has not changed much in all the lakes that are not wastewater recipients.

In contrast, the nitrogen concentration has generally decreased because there is a considerable proportion of cultivated land in most of the lake catchments, and leaching from cultivated land has generally decreased (see Chapters 5 and 8).

7.2 Trend in water quality

Phosphorus and nitrogen concentrations

The trends in lake water phosphorus and nitrogen concentrations to some extent follow the trends in inflow concentrations.

The phosphorus concentration in the most strongly polluted lakes has decreased markedly (Figure 7.3) from around 0.4 mg P/l to 0.2 mg P/l for the 10% percentile.

The trend in lakewater nitrogen concentration is less clear, although the nitrogen concentration has decreased in lakes with particularly high nitrogen concentrations (Figure 7.3).

The difference in the trend for phosphorus and nitrogen concentrations in the lakes is due to the fact that phosphorus and nitrogen behave differently in the lakes.

Large amounts of phosphorus are often accumulated in the lake sediment. Release of this phosphorus from the sediment pool delays the reduction in phosphorus concentration in the water, often by several decades.

Nitrogen does not accumulate in the lakes in the same way, and changes in lakewater content of nitrogen compounds therefore occur rapidly following changes in the inflow concentrations. As a result of internal processes in the lakes, however, the changes in lakewater concentrations will be smaller than the changes in the inflow concentrations. This is due to the fact that nitrate in the lakes will be partly transformed to atmospheric nitrogen, and that quite a number of lake algae can take up atmospheric nitrogen and thereby counteract a reduction in loading.

In shallow lakes the nitrogen concentration will often decrease if algal biomass decreases, for example due to reduced phosphorus input. This is due to the fact that a larger proportion of the nitrogen will not be taken up by the algae but will remain in the form of nitrate and can thereby be more easily transformed to atmospheric nitrogen (N_2). A reduction in phosphorus loading of shallow lakes will therefore often lead to a reduction in the nitrogen content of the lake and to reduced transport of nitrogen compounds to downstream lakes and fjords.

AQUATIC ENVIRONMENT 2004 – Figure 7.3

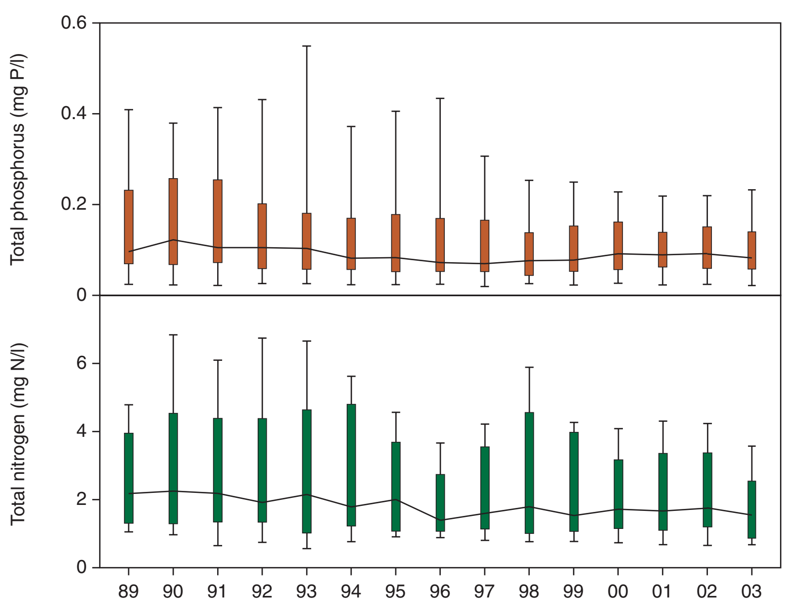


Figure 7.3 Phosphorus and nitrogen concentrations in the monitoring lakes over the period 1989–2003. The curves connect the median values for the individual years. The 10% and 25% percentiles are also shown (*Jensen et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 7.4

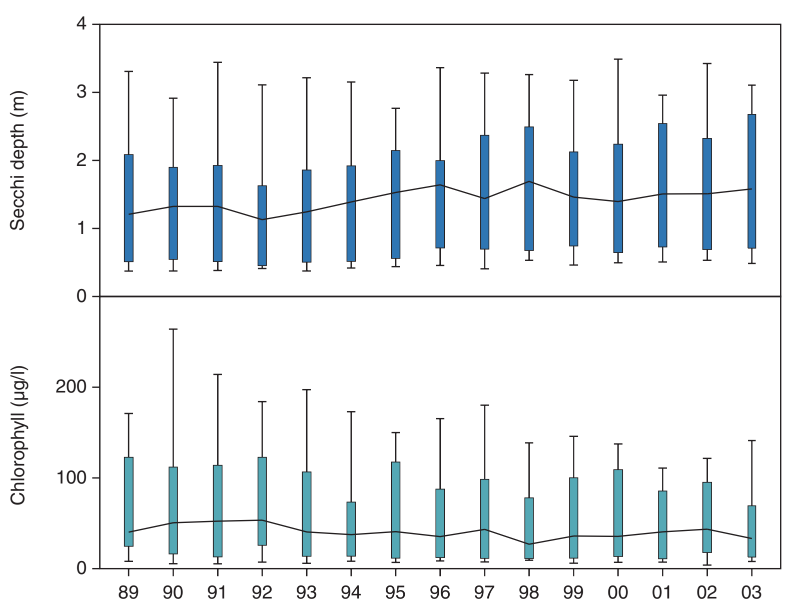


Figure 7.4 Trend in Secchi depth and chlorophyll concentration in the surface water of the monitoring lakes during the summer period over the period 1989–2003. The curves connect the median values for the individual years. The 10% and 25% percentiles are also shown (*Jensen et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Table 7.3

LAKES 1989–2003	Secchi depth (m)		Chlorophyll (mg/l)		Algal volume (mm³/l)	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
1989–95	1.44	1.38	0.077	0.050	14.1	10.4
1996–02	1.63	1.61	0.057	0.037	10.7	9.5
2003	1.73	1.58	0.050	0.033	10.1	4.8

Table 7.3 Mean and median Secchi depth, chlorophyll and algal volume in the surface water of the monitoring lakes during the summer period (1/5–30/9) for the periods 1989–95 and 1996–2002 and for 2003 (data from *Jensen et al., 2004*).

Secchi depth and algal biomass

The generally decreasing level of nutrients in the lakes since 1989 has led to an increase in Secchi depth and a decrease in chlorophyll content (Figure 7.4). The annual mean Secchi depth for all the lakes has increased from 1.7 m in the period 1989–1995 to 2.0 m in 2003, while the summer mean Secchi depth has increased from 1.4 m to 1.7 m (Table 7.3), corresponding to a 21% improvement in Secchi depth.

AQUATIC ENVIRONMENT 2004 – Table 7.4

CHANGES IN LAKES 1989–2003	Annual mean in inlet		Annual mean in lake		Summer mean (1/5–30/9) in lake			
	Total phosphorus	**Total nitrogen**	**Total phosphorus**	**Total nitrogen**	**Secchi depth**	**Chloro-phyll**	**Algal volume**	**Yellow algae**
Søby Sø	0	0	0	0	–	0	0	0
Holm Sø	– – – –	– –	0	0	0	0	0	+ +
Maglesø	0	0	0	– – –	0	0	0	0
Nors Sø	0	– –	0	0	0	0	0	0
Ravn Sø	– – –	– – – –	– – – –	– – – –	0	0	–	0
Søholm Sø	+ + +	0	– – –	0	0	0	0	+ +
Kvie Sø	– –	– –	0	0	0	0	0	+ +
Bastrup Sø	0	– – – –	0	– – – –	+ + + +	0	0	+ +
Hornum Sø	0	0	0	0	0	0	0	–
Ørn Sø	– –	– – –	– – – –	– – – –	0	– –	0	+ + +
Furesøen	– – – –	– – – –	– – – –	– – – –	+ + + +	0	–	0
Fårup Sø	0	– –	– – –	– – –	+ + + +	– – – –	– – –	0
Damhussøen	0	0	– – –	0	+ +	–	0	0
Bryrup Langsø	– – –	0	– – – –	– – –	0	0	0	+ +
Hinge Sø	0	– – – –	0	– – – –	0	0	0	0
Tissø	– – – –	– – –	+	0	+ + + +	0	0	0
Engelsholm Sø	0	– – –	– – – –	– – – –	+ + +	– – –	– – – –	+ +
Bagsværd Sø	0	0	– – – –	0	0	0	– –	0
Borup Sø	0	– – –	– – –	– – – –	+ + +	– – –	– –	+ +
Arreskov Sø	– –	– – –	0	0	+ +	0	0	0
Tystrup Sø	– – – –	– – – –	– – – –	– – –	0	+ +	+ +	0
Arresø	– – – –	– – – –	– – – –	– – – –	0	– – –	– – –	0
Vesterborg Sø	0	– –	– – – –	– – –	+ + + +	– – – –	– – –	0
St. Søgård Sø	– –	– – – –	– – – –	– – –	0	– –	–	0
Utterslev Mose	– – – –	– – – –	0	0	0	0	0	0
Søgård Sø	0	– – –	– – – –	– – –	+ + + +	– – –	0	0
Gundsømagle Sø	– – – –	– – – –	– – – –	– – – –	+	– –	0	+ + +
No. of lakes with +	**1**	**0**	**1**	**0**	**12**	**1**	**1**	**9**
No. of lakes with –	**13**	**13**	**16**	**16**	**1**	**10**	**9**	**1**

Table 7.4 Changes in water quality parameters in the monitoring lakes (27 freshwater lakes) over the period 1989–2003. Changes are indicated by + (higher values) or – (lower values). 0 indicates unchanged. The greater the number of pluses or minuses, the more certain the change (90, 95, 99 and 99.9% certainty for 1, 2, 3 and 4 pluses/minuses, respectively). Brackish lakes are not shown here as they have only been included in the monitoring programme since 1999 (data from *Jensen et al., 2004*).

The improvement in Secchi depth is attributable to a reduction in algal biomass in the monitoring lakes. This is reflected in a 45% reduction in annual mean chlorophyll concentration in the lakewater in 2003 relative to the period 1989–1995 and a corresponding 35% reduction in the summer mean concentration. The mean and median values for Secchi depth, chlorophyll concentration and algal volume in the surface water during the summer period are shown in Table 7.3. The figures give a very consistent picture of a general although moderate improvement in the environmental state of the lakes.

Overview of the trend in water quality
Key data on water quality in the individual lakes demonstrate considerable general improvement in the quality of the water in the monitoring lakes (Table 7.4). In approximately half of the lakes the biological conditions have changed towards a less polluted state. Either the Secchi depth has increased and/or the algal biomass has decreased with the consequent possibility for greater distribution of submerged macrophytes, or the composition of the algal community in the lakewater has changed towards greater abundance of algae that are typical for non-eutrophic lakes, e.g. yellow algae.

AQUATIC ENVIRONMENT 2004 – Table 7.5

LAKE CHARACTERISTICS 2003	Lake area (km^2)	Mean depth (m)	Catchment area (km^2)	Cultivated area (% of catchment)	Phosphorus input (g P/m^2/yr)	Total phosphorus (µg P/l)	Chlorophyll (µg/l)	Secchi depth (m)	Objective compliance
Søby Sø	0.73	2.8	0.8	15	0.04	25	6	3.1	No
Holm Sø	0.12	0.8	1.0	4	0.03	22	1	1.5	Yes
Maglesø	0.15	3.6	1.2	48	0.02	20	8	2.6	Yes
Nors Sø	3.47	3.6	20.5	43	0.01	32	14	2.7	Yes
Ravn Sø	1.82	15.0	57.2	70	0.48	21	9	3.3	No
Søholm Sø	0.26	6.5	5.7	54	0.49	58	21	1.4	No
Kvie Sø	0.30	1.2	0.6	20	0.01	82	13	1.6	No
Bastrup Sø	0.33	3.5	4.1	58	0.08	64	28	2.8	No
Hornum Sø	0.11	1.5	7.9	76	0.17	46	8	2.9	Yes
Ørn Sø	0.42	4.0	56.0	41	8.97	60	35	1.5	No
Furesøen	7.31	16.5	79.0	18	0.06	92	26	3.3	No
Fårup Sø	0.99	5.6	13.8	73	0.93	79	16	2.6	No
Damhussøen	0.46	1.6	56.9	10	0.09	73	8	1.8	Yes
Bryrup Langsø	0.38	4.6	48.2	69	1.34	63	22	2.1	No
Hinge Sø	0.91	1.2	53.8	81	2.31	118	141	0.5	No
Tissø	12.3	8.2	417.9	68	0.55	107	35	2.0	No
Engelsholm Sø	0.44	2.6	16.1	77	0.83	69	53	1.6	No
Bagsværd Sø	1.21	1.9	6.8	2	0.03	83	49	0.5	No
Borup Sø	0.10	1.1	7.6	54	1.63	98	33	1.2	(Yes)
Arreskov Sø	3.17	1.9	24.9	43	0.17	233	173	1.3	No
Tystrup Sø	6.62	9.9	682.5	68	2.50	120	37	2.7	No
Arresø	39.9	3.1	216.1	44	0.29	228	101	0.7	No
Vesterborg Sø	0.21	1.4	30.3	69	1.43	140	69	0.7	No
St. Søgårdsø	0.60	2.7	44.9	75	1.17	232	60	0.8	No
Utterslev Mose	0.30	1.1	1.25	8	0.14	232	103	0.6	No
Søgård Sø	0.27	1.6	22.7	87	1.61	193	135	0.5	No
Gundsømagle Sø	0.32	1.2	66.0	70	4.62	267	146	0.4	No
Ulvedybet	5.80	1.0	55.4	60	0.17	205	12	1.4	Yes
Ferring Sø	3.17	1.4	17.0	70	0.13	253	167	0.3	No
Ketting Nor	0.39	(1.0)	18.9	82	0.26	91	32	0.6	No
Nakskov Indrefjord	0.69	0.6	140.9	79	1.41	174	30	0.9	Yes
Maximum	**39.87**	**16.5**	**682.5**	**87**	**8.97**	**267**	**173**	**3.3**	
Mean	**3.01**	**3.6**	**70.2**	**53**	**1.03**	**115**	**51**	**1.6**	
Minimum	**0.10**	**0.6**	**0.6**	**2**	**0.01**	**20**	**1**	**0.3**	

Table 7.5 Characteristics of the 31 monitoring lakes (27 freshwater and 4 brackish). The maximum, mean and minimum values are shown for each parameter at the bottom of the table. The values for phosphorus input, total phosphorus, chlorophyll and Secchi depth are from 2003. Chlorophyll and Secchi depth are summer mean values, the rest are annual mean values (data from *Jensen et al., 2004*).

Other biological conditions

Only minor changes have been recorded in the other biological conditions in the lakes (*Jensen et al., 2004*). However, the amount of zooplankton in the lakes has decreased, probably mainly as a result of the reduction in algal biomass. The amount of large daphnia has increased, though, which correlates with the reduction in the population of zooplanktivorous fish (e.g. roach) and with the apparent increase in the population of carnivorous fish. Under these conditions, the large daphnia are less likely to be eaten and can therefore better help hold down the algal biomass through grazing on the algae in the water.

No general changes have taken place as to the submerged macrophytes in the lakes. It could be expected that the increased Secchi depth in many of the lakes would have led to enhanced distribution of submerged macrophytes due to improvement in light conditions for the plants.

7.3 Quality objectives and current state

The Regional Plans drawn up by the Counties stipulate environmental quality objectives for the lakes. In connection with these the Counties stipulate guidelines for reducing the nutrient sources that can be regulated via regional planning. The quality objectives are usually set for Secchi depth and phosphorus concentration and possibly also for the chlorophyll content of the lakewater.

The Secchi depth requirement for the monitoring lakes ranges from 0.8 m to 4 m, while the phosphorus requirement ranges from 0.025 to 0.125 mg P/l.

Both the actual environmental quality of the lakes and the state that they would have in the absence of all forms of pollution are highly dependent on the depth conditions in the lake and of the water's residence time in the lake.

Table 7.5 summarizes some of the key data on each lake to characterize both the natural preconditions and the general environmental conditions in the lake. The table also indicates whether the lake complied with its environmental quality objective in 2003.

Seven to eight of the 31 monitoring lakes (27 freshwater and 4 brackish) met their quality objective in 2003. Quality objective compliance among the monitoring lakes is thus at the same level as for Danish lakes in general, it being known that approx. 1/3 of all Danish lakes met their quality objective in 1997 and 2001 *(Jensen et al., 2004*).

8 Watercourses

The main factor affecting the environmental state of most Danish watercourses is the physical changes that have taken place over the years through channelization and damming, as well as through the watercourse maintenance that continues to be carried out to enable cultivation of the adjoining land.

Pollution by organic matter from wastewater discharges used to be the other major cause of pollution, but this problem has largely been dealt with through the wastewater treatment implemented over the past few decades. The nutrient content of the water is of only minor importance as regards the environmental state of Danish watercourses.

8.1 Watercourse biological quality

Watercourse quality in 2003

The biological quality of the watercourses is determined yearly from the composition of the macroinvertebrate fauna at approx. 1,050 localities. The assessment is made using the Danish

AQUATIC ENVIRONMENT 2004 – Figure 8.1

Fauna class DSFI	No. of stations
1	13
2	38
3	122
4	413
5	315
6	68
7	82

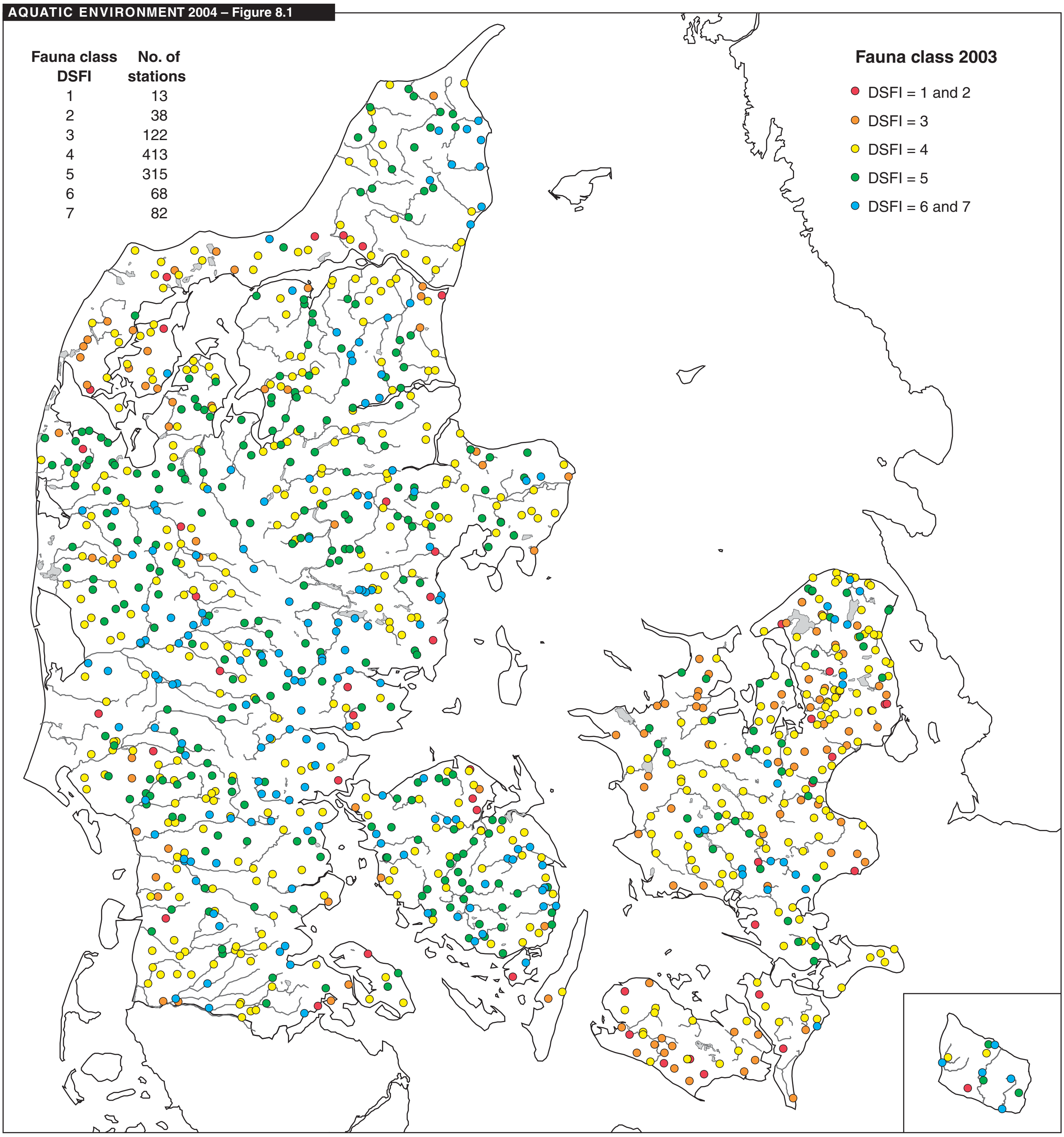


Figure 8.1 Environmental status of Danish watercourses in 2003 assessed from the occurrence of macroinvertebrates using the Danish Stream Fauna Index (DSFI). Blue circles (DSFI 6 and 7) indicate watercourses with a natural or only slightly affected macroinvertebrate fauna. Red circles (DSFI 1 and 2) indicate severely polluted watercourses *(Bøgestrand (ed.), 2004)*.

Stream Fauna Index (DSFI), which rates the fauna class on a 7-point scale. With fauna class 7 the fauna is very diverse with many clean-water species; the fauna is almost equivalent to that which could be expected if the watercourse was completely unaffected by human activities. With fauna classes 1 and 2 the watercourses are very polluted. In order to fulfil the environmental quality objectives stipulated in the County Regional Plans, most watercourses have to be at least fauna class 5.

In 2003, just over 44% of the watercourses were fauna classes 5, 6 or 7, which are characteristic for relatively clean and physically varied watercourses (Figure 8.1). In a further 40% of the watercourses the macroinvertebrate fauna was moderately affected (fauna class 4).

Less than 16% of the watercourses were fauna classes 1, 2 or 3, which characterize a very poor environmental state. By far the majority (70%) of these watercourses with poor environmental quality were small watercourses with a width of less than 2 m. Of the watercourses with a width exceeding 5 m, 71% were fauna class 4 or more.

The areas of Denmark in which watercourse quality was best were Jutland, Funen and Bornholm (Figure 8.1). The generally better state of these watercourses means that approx. 56% of the watercourses in these areas met their environmental quality objective. In contrast, only just over a third of the watercourses on Zealand, Lolland, Falster and Møn met their environmental quality objective. At the national level, quality objective compliance was 51% in 2003. That the compliance rate exceeds the percentage of fauna class 5, 6 and 7 watercourses is due to the fact that the quality objective for some watercourses is only fauna class 4.

Trend in watercourse biological quality and quality objective compliance

The monitoring has been performed at the same network of approx. 1,050 watercourse stations since 1999. The environmental state of the watercourses has improved over the period 1999–2003 (Figure 8.2) with an increasing proportion of the watercourses being fauna classes 5, 6 or 7. The proportion of watercourses that are unaffected or only slightly affected has increased from just under 35% to just over 44% during this period.

Due to the improvement in watercourse biological quality over the period 1999–2003, quality objective compliance at the national level has increased from 39% to 51%. The improvements have been gradual and have taken place over the whole period. Moreover, the improvements have taken place over the whole country. Compliance with watercourse quality objectives increased from 43% to 55% in Jutland and Funen and from 27% to 37% on Zealand, Lolland, Falster and Møn.

The improvement in biological state has also taken place in both small and large watercourses. The proportion of fauna class 5–7 watercourses has increased from 33% to 42% for the small (up to 5 m wide) watercourses and from 44% to 53% for the large (over 5 m wide) watercourses.

The improvements in watercourse environmental state over the period 1999–2003 should be viewed in the light of the fact that regular improvements have also taken place in the preceding decades as a result of improved wastewater treatment, cessation of unlawful agricultural discharges and the introduction of more environmentally sound watercourse maintenance. The high freshwater runoff during the five preceding years might have contributed to the improved environmental state of the watercourses.

AQUATIC ENVIRONMENT 2004 – Figure 8.2

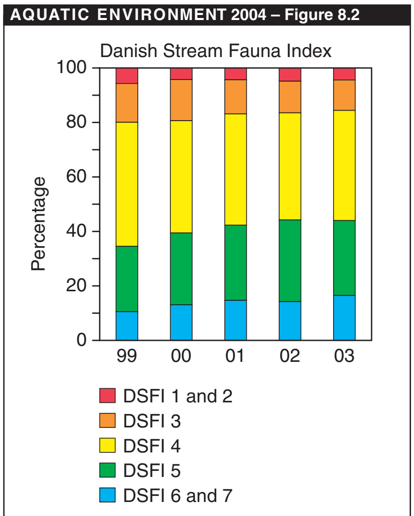


Figure 8.2 Environmental state of Danish watercourses over the period 1999–2003 assessed using the Danish Stream Fauna Index (DSFI). Blue and green indicate watercourses whose environmental state is good (fauna classes 5, 6 and 7) *(Bøgestrand (ed.), 2004)*.

The improvements in the environmental state of the watercourses can be expected to continue in the coming years. The main reasons for this expectation are:

- The efforts made so far to improve wastewater treatment and to re-create more natural physical conditions in the watercourses have not yet taken full effect
- Further improvements in wastewater treatment are expected, especially regarding wastewater from sparsely built-up areas
- Physical conditions are expected to improve in many of the watercourses in connection with implementation of Action Plan on the Aquatic Environment III.

8.2 Nitrogen in watercourses

Status in 2003

On average, the nitrogen concentration in watercourses draining cultivated catchments or receiving significant point-source discharges in 2003 was approximately 4-fold greater than the background level measured in watercourses draining semi-natural areas (Table 8.1). The difference between watercourses located in cultivated catchments devoid of point sources and watercourses located in cultivated catchments with significant point-source loading from urban wastewater is minor.

The proportion of watercourses with a low nitrogen concentration is relatively high in the sandy parts of mid and western Jutland and of northern Zealand, while there is a predominance of high concentrations in the clayey areas such as southern Zealand, Lolland and Falster (Figure 8.3). On sandy soils the watercourses are primarily fed by groundwater, while in the clayey areas there is more near-surface runoff, whereby the surplus nitrogen in the soil has a short transport path to the watercourse. On the sandy soils the nitrogen is therefore a long time underway from the root zone to the watercourse, possibly via the groundwater. Due to the long transport time, nitrogen removal can take place via denitrification.

AQUATIC ENVIRONMENT 2004 – Figure 8.3

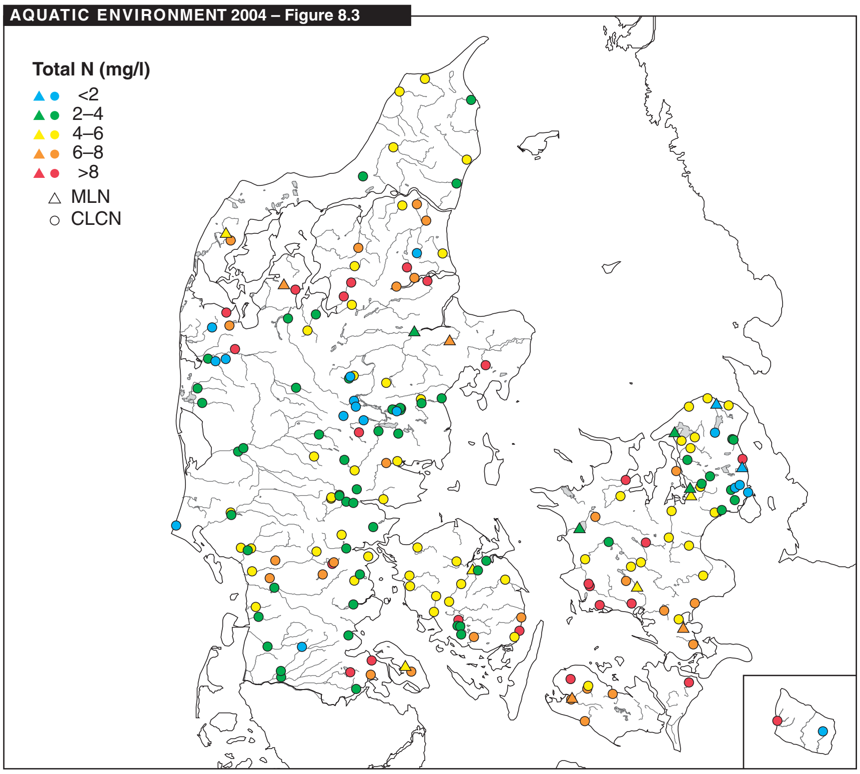


Figure 8.3 Concentration of total nitrogen (flow-weighted annual mean values) in watercourses in 2003. The station network to which each station belongs is indicated.
MLN: Marine loading network.
CLCN: Catchment loading category network *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Figure 8.4

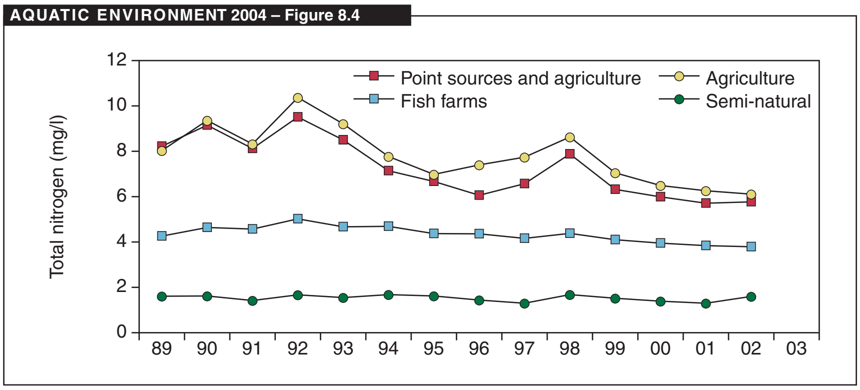


Figure 8.4 Trend in nitrogen concentration in watercourses in different catchment loading categories over the period 1989–2002 *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Table 8.1

CATCHMENT CATEGORY	No. of watercourses	Nitrogen concentration (mg N/l)	Area coefficient (kg N/ha)
Semi-natural	10	1.2 (±0.7)	1.3 (±0.6)
Point sources and agriculture	63	4.6 (±2.2)	10.7 (±6.9)
Agriculture	108	5.7 (±2.6)	9.2 (±5.0)

Table 8.1 Mean total nitrogen concentration and area coefficient in watercourses in different catchment loading categories in 2003. Standard deviation is shown in parentheses *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Table 8.2

CATCHMENT CATEGORY	No. of stations	No. with a significant fall	No. with a significant increase	Percentage change in concentration	Percentage change in transport
Semi-natural	7	4	0	–16±19	–21±23
Agriculture	63	50	0	–29±3	–35±4
Point sources and agriculture	75	68	0	–33±4	–36±4
Fish farms	15	11	1	–23±6	–24±6
Total	**164**	**136**	**2**	**–30±3**	**–34±3**

Table 8.2 Changes in nitrogen concentration and transport in watercourses in different catchment loading categories over the period 1989–2003. Mean values with 95% confidence limits (*Bøgestrand (ed.), 2004*).

The mean concentration of total nitrogen in watercourses in clayey catchments is nearly 2 mg/l higher than in watercourses in sandy catchments.

Trend since 1989

The nitrogen concentration has decreased markedly in watercourses in cultivated catchments both with and without significant discharges of urban wastewater (Figure 8.4 and Table 8.2). In watercourses receiving significant discharges from freshwater fish farms the reduction in nitrogen concentration is minor. The concentration in these watercourses has been relatively low during the whole period, however, as the fish farming industry is concentrated in groundwater-fed watercourses located in sandy catchments. The watercourses draining semi-natural catchments exhibit no trend in nitrogen concentration.

8.3 Phosphorus in watercourses

Status in 2003

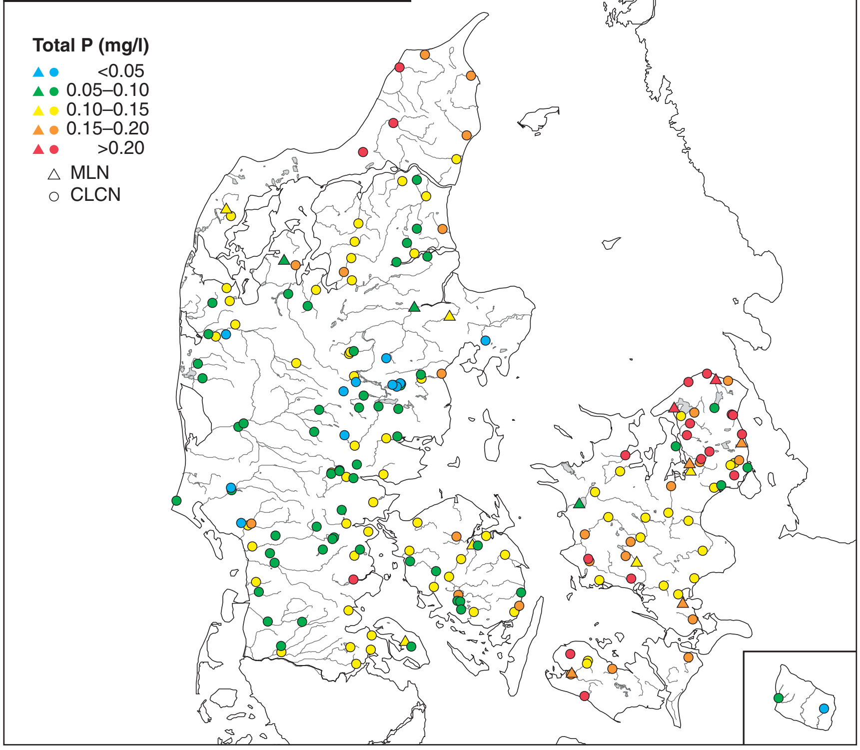
On average, the mean phosphorus concentration in watercourses receiving wastewater from wastewater treatment plants in 2003 was 3-fold greater than the level in watercourses draining semi-natural areas. In watercourses in agricultural catchments without urban wastewater the concentration was twice that in watercourses draining semi-natural areas (Table 8.3).

High phosphorus concentrations are particularly likely to be found in the densely populated parts of northern Zealand (Figure 8.5), but the watercourse phosphorus concentration is also relatively high in other parts of Zealand as the high population density results in relatively large discharges from wastewater treatment plants and sparsely built-up areas, and low flow

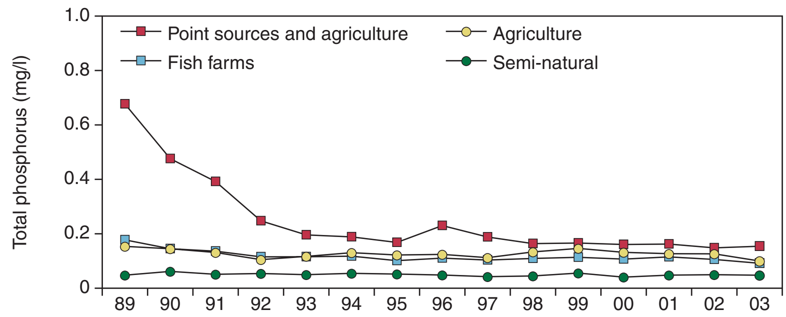
Figure 8.5 Concentration of total phosphorus (flow-weighted annual mean values) in watercourses in 2003. The station network to which each station belongs is indicated.
MLN: Marine loading network.
CLCN: Catchment loading category network *(Bøgestrand (ed.), 2004).*

Figure 8.6 Trend in phosphorus concentration in watercourses in different catchment loading categories over the period 1989–2003 *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Figure 8.5



AQUATIC ENVIRONMENT 2004 – Figure 8.6



in the watercourses results in poor dilution of the discharged wastewater. The phosphorus concentration is also high in Vendsyssel. In the more sparsely populated regions of mid and western Jutland where flow in the watercourses is higher, the phosphorus concentration is lower.

Trend since 1989

The concentration of total phosphorus in watercourses receiving wastewater decreased markedly during the first half of the 1990s and is now only slightly higher than in catchments only affected by cultivation (Figure 8.6 and Table 8.3). The decrease is due to the measures implemented to reduce pollution from urban wastewater and industrial discharges, both in connection with the Action Plan on the Aquatic Environment and specific regional measures in the catchments of lakes and fjords. In the watercourses affected by freshwater fish farms the phosphorus concentration has decreased slightly due to reduction in discharges from the fish farms. The watercourses draining semi-natural catchments and cultivated catchments without urban wastewater exhibit no trend in phosphorus concentration.

The trend in phosphorus concentration in the watercourses affected by wastewater should be viewed in the light of the fact that phosphorus removal had already been implemented at many wastewater treatment plants in the catchments of lakes and fjords prior to 1989. The phosphorus concentration in the watercourses affected by wastewater was thus far higher before 1980 than in 1989 (Figure 8.6), and the reductions shown in Table 8.4 would have been far greater for watercourses with point-source loading if the starting point for the comparison had been the levels in 1980 or earlier.

AQUATIC ENVIRONMENT 2004 – Table 8.3

CATCHMENT CATEGORY	No. of watercourses	Phosphorus concentration (mg P/l)	Area coefficient (kg P/ha)
Semi-natural	10	0.05 (±0.03)	0.06 (±0.04)
Point sources and agriculture	63	0.16 (±0.08)	0.35 (±0.18)
Agriculture	74	0.10 (±0.04)	0.17 (±0.13)

Table 8.3 Mean phosphorus concentration and area coefficient in watercourses in different catchment loading categories in 2003. Standard deviation is shown in parentheses *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Table 8.4

CATCHMENT CATEGORY	No. of stations	No. with a significant fall	No. with a significant increase	Percentage change in concentration	Percentage change in transport
Semi-natural	7	0	1	0±13	+7±14
Agriculture	38	9	4	–13±8	–13±7
Point sources and agriculture	75	60	0	–43±6	–39±6
Fish farms	15	9	0	–28±10	–31±9
Total	**164**	**93**	**5**	**–28±4**	**–27±4**

Table 8.4 Changes in phosphorus concentration and transport in watercourses in different catchment loading categories over the period 1989–2003. Mean values with 95% confidence limits (*Bøgestrand (ed.), 2004*).

9 Marine waters

The pollution pressure on Danish marine waters is mainly attributable to inputs of nitrogen and phosphorus to the sea from land-based sources and via the atmosphere. The shallow Danish coastal and inner marine waters are more vulnerable to eutrophication than most of the other marine waters elsewhere in the world because water exchange with the open sea is often limited, and because stratification of the water column often limits the input of oxygen to the bottom water. In addition to nutrients, the biological conditions in the marine waters are also affected by physical changes such as dredging, raw materials extraction and marine dumping of seabed materials. On top of this, fishery affects both the physical and biological conditions. Finally, hazardous substances are input to the marine waters by shipping, offshore activities and wastewater and via the air.

The monitoring programme

The NOVA-2003 subprogramme for marine waters encompasses hydrographic, chemical and biological monitoring subdivided into three main groups of investigations:

- Measurements in the water column
- Submerged aquatic vegetation and benthic invertebrates
- Heavy metals and hazardous substances.

As is apparent from Figure 1.1, the monitoring focuses on the coastal waters and the inner marine waters, although as regards water chemistry in particular, also on stations in the North Sea.

The year 2003

The year 2003 differed from an average year in many respects. The most obvious difference was the lack of reoxygenation of the sediment in the winter in many fjords and coastal waters. In addition, the weather was characterized by a lack of strong winds, a warm summer and low precipitation except during the early summer. Riverine runoff of nutrients was low due to the low winter precipitation and the effects of the Action Plans on the Aquatic Environment. The nutrient concentrations in the water were therefore low. Nevertheless, relatively severe oxygen deficit was still recorded in the inner marine waters. This is probably mainly attributable to the lack of wind and the warm summer, but the oxygen deficit in 2003 might have been enhanced by the after-effects of the extreme oxygen deficit in 2002.

AQUATIC ENVIRONMENT 2004 – Table 9.1

SOURCE APPORTIONMENT 2003	Organic matter (BOD_5) (tonnes/yr)	Nitrogen (tonnes/yr)	Phosphorus (tonnes/yr)
Background loading	5,600	5,400	240
Leaching from agriculture	2,300	40,100	440
Sparsely built-up areas*	3,700	900	220
Point sources to inland waters	5,500	3,400	380
Retention in inland waters	-	–4,800	–50
Total riverine inputs	**approx. 17,000**	**45,000**	**1,230**
Wastewater direct to the sea	3,700	2,600	320
Marine and saltwater fish farms	1,560	300	30
Total to the sea	**approx. 24,000**	**47,900**	**1,580**

Table 9.1 Input of organic matter, nitrogen and phosphorus to the sea via riverine runoff and direct discharges in 2003 (rounded figures). * Wastewater from rural properties outside the sewerage catchment. Wastewater data are from *Danish EPA (2004). (Bøgestrand (ed.), 2004).*

9.1 Nutrient and organic matter inputs to marine waters

Inputs in 2003

In 2003, total inputs to Danish marine waters via riverine runoff and direct discharges amounted to 10,660 million m^3 water, 47,900 tonnes nitrogen, 1,580 tonnes phosphorus and approx. 24,000 tonnes organic matter (BOD_5). Source apportionment of these nutrient and organic matter inputs is shown in Table 9.1. Inputs of all three substances were considerably lower than in 2002.

The diffuse sources (i.e. natural background loading and leaching from fields) accounted for 87% of the total nitrogen sources other than the air in 2003. The corresponding figure for phosphorus was 42%.

The proportion of the total inputs accounted for by diffuse sources is least in the most densely populated areas, where the proportion accounted for by point sources is large. In the case of BOD_5, considerable decomposition takes place during transport in watercourses and lakes, and source apportionment and hence calculation of the diffuse load is therefore very uncertain and less relevant at the national level. The diffuse sources will be greatest in years with high freshwater runoff, both in relative and absolute terms.

The loss of nitrogen from the catchment expressed as the area coefficient (loss via riverine runoff divided by the catchment area) was approx. 10 kg/ha for Denmark as a whole in 2003, while the mean concentration was 4.2 mg N/l. The corresponding figures for phosphorus were approx. 0.29 kg P/ha and 0.115 mg P/l, respectively.

The diffuse loss of nitrogen expressed in terms of the area coefficient has been greatest in the catchments of Limfjorden and Mariager Fjord. The losses to parts of the North Sea and in Zealand, parts

AQUATIC ENVIRONMENT 2004 – Figure 9.1

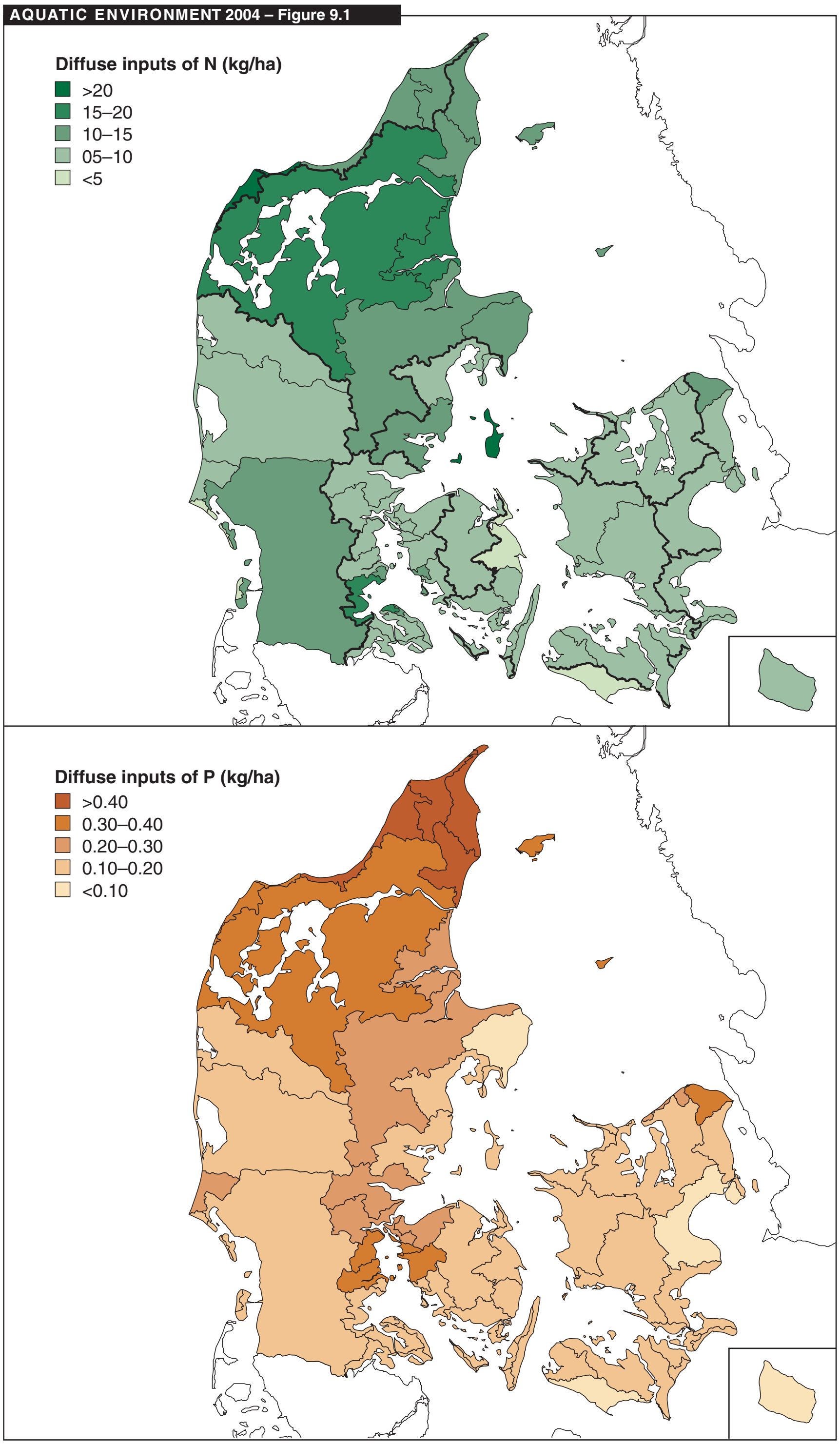


Figure 9.1 Diffuse inputs of nitrogen (upper panel) and phosphorus (lower panel) to inland waters in 2003 *(Bøgestrand (ed.), 2004).*

AQUATIC ENVIRONMENT 2004 – Table 9.2

N AND P INPUTS TO MARINE WATERS 2003	All Danish marine waters 105,372 km²		Inner Danish marine waters 39,203 km²	
	Nitrogen (tonnes/yr)	Phosphorus (tonnes/yr)	Nitrogen (tonnes/yr)	Phosphorus (tonnes/yr)
Riverine runoff	45,000	1,230	31,600	852
Direct discharges to the sea	2,900	350	2,620	319
Total	**47,900**	**1,580**	**34,200**	**1,171**
Input via the atmosphere	124,000	approx. 400	39,000	approx. 130

Table 9.2 Inputs of nitrogen and phosphorus to Danish marine waters from the Danish landmass via riverine runoff and direct discharges to the sea in 2003 shown together with inputs via the atmosphere. The areas and atmospheric inputs include the Swedish parts of the Kattegat and the Øresund (*Ærtebjerg et al., 2004*).

of eastern Jutland and on Funen have been relatively low (Figure 9.1).

The diffuse loss of phosphorus was greatest in nothern Jutland, while in the remainder of the country the pattern was similar to that for nitrogen.

Input to the Danish marine waters as a whole and to the inner marine waters

Total inputs of nitrogen and phosphorus from riverine runoff and point sources from Denmark are shown in Table 9.2 for Danish marine waters as a whole and for the inner marine waters (the Kattegat and the Belt Sea). Nutrient exchange with the adjoining marine waters and inputs from Sweden and Germany are not included, but are described in *Rasmussen et al., 2003*.

The greatest nitrogen input is via the atmosphere. Considering the inner marine waters alone, however, nitrogen inputs from Denmark via riverine runoff and point sources are almost as great as atmospheric inputs. In the fjords, inputs from the catchments dominate.

The main phosphorus input is riverine runoff, most of which derives from leaching from the soil (see Chapters 4 and 8). The total input from wastewater remains considerable, however. The magnitude of phosphorus input via the atmosphere is very uncertain, but is generally of minor importance.

Trend in nutrient inputs to marine waters

Nitrogen and phosphorus inputs via riverine runoff and direct discharges to the coastal waters have been determined every year since 1989 (Figure 9.2). Diffuse loading is the main source of nitrogen input from land to the coastal waters via riverine runoff and direct discharges, accounting for a mean of approx. 80% over the period 1989–2003, and clearly correlating with freshwater runoff. In the case of phosphorus, diffuse loading accounted for approx. 30% of the total input as an average for the period 1989-2003, although the significance of this source has increased markedly in line with improved wastewater treatment.

The great improvement in wastewater treatment is clearly apparent in that total phosphorus discharges from direct and indirect point sources have decreased from approx. 9,000 tonnes P in 1981–88 to approx. 1,000 tonnes P in 2003, a reduction of approx. 90%. Correspondingly, total inputs of nitrogen from direct and indirect point sources decreased from approx. 28,000 tonnes in 1981–88 to approx. 7,000 tonnes in 2003, a reduction of approx. 75%. Since the mid 1990s, inputs of nitrogen and phosphorus from point sources have only decreased slightly (Figure 9.2).

For Denmark as a whole, runoff-weighted diffuse input of nitrogen has decreased by approx. 2.5 mg N/l (compare with Figure 8.4). In contrast, no change has been detected in diffuse phosphorus input at the national level.

Since implementation of the first Action Plan on the Aquatic Environment total inputs of both nitrogen and phosphorus to coastal waters via riverine runoff and direct discharges have decreased. The decrease in phosphorus inputs is solely attributable to the markedly improved treatment of wastewater, while the decrease in nitrogen inputs is also due to a reduction in diffuse loading.

After correction for interannual variation in freshwater runoff, the reduction in total nitrogen input to Danish marine waters via riverine runoff and direct discharges over the period 1989–2003 is 43%. With 95% probability the reduction lies between 33% and 61%. During the same period total phosphorus input decreased by 81%. With 95% probability the reduction lies between 47% and 100%.

Due to phosphorus removal at wastewater treatment plants, total phosphorus input to marine waters has decreased from almost 10,000 tonnes/yr in the 1980s to approx. 2,000 tonnes/yr. There has not been any reduction in phosphorus leaching from cultivated land, however. The total reduction in phosphorus input since 1989 is calculated to be 80% (*Bøgestrand (ed.), 2004*), both with and without correction for freshwater runoff.

Leaching of nitrogen from cultivated land has decreased by approx. 38–50% in years with normal precipitation (*Grant et al., 2004*).

As regards algal biomass in the marine waters, however, it is the specific input in tonnes per year that is important. In the absence of correction for freshwater runoff it is not possible to demonstrate any decrease in total nitrogen input in tonnes per year with 95% probability (*Bøgestrand (ed.), 2004*). This is because nitrogen leaching is closely coupled to the very variable freshwater runoff and that the years 1998–2002 were very wet.

AQUATIC ENVIRONMENT 2004 – Figure 9.2

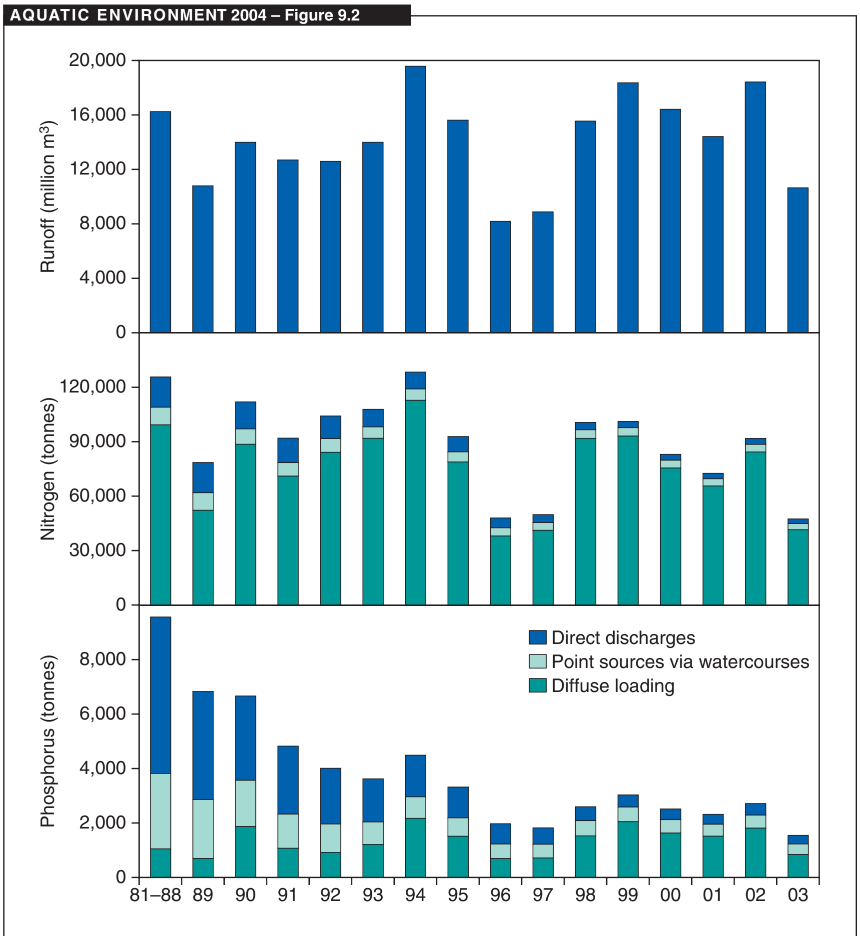


Figure 9.2 Freshwater runoff and the total inputs of nitrogen and phosphorus via riverine runoff and direct wastewater discharges to Danish marine waters over the period 1989–2003 shown together with the mean for the period 1981–1988 *(Bøgestrand (ed.), 2004)*.

9.2 Retention and transport of nitrogen and phosphorus in fjords

Part of the nitrogen and phosphorus led to the fjords from the land is turned over or sedimented out in the fjords and thus does not contribute to pollution of the adjoining marine waters. Calculations of this turnover and transport are provided elsewhere (*Ærtebjerg et al., 2004*).

Retention in the fjords

The proportion of the nitrogen and phosphorus inputs retained in each of eight fjords over the period 1985–2003 is illustrated in Figure 9.3. From the figure it can be seen that retention of nitrogen is nearly always more than 80% in Roskilde Fjord and around 50% in Limfjorden, Mariager Fjord and Ringkøbing Fjord.

As regards fjords, the same pattern thus applies as for lakes, i.e. due to the long retention time of the water a great proportion of the nitrogen load is not transported onwards because nitrate is reduced in the fjord sediment to atmospheric nitrogen.

The retention of phosphorus (Figure 9.3) differs. In many of the fjords there have been short or long periods in which no phosphorus was retained. In the early 1990s in particular, when phosphorus input from the land was markedly reduced, phosphorus transport out of the fjords exceeded phosphorus input. This is attributable to the phosphorus that had accumulated in the fjord sediment during previous decades of high wastewater loading. After phosphorus input has decreased, part of the sediment phosphorus pool has dissolved in the fjord water. This has delayed improvement in the environmental state of the fjords. In the longer term, though, a fjord will retain a larger or smaller proportion of the incoming phosphorus load in the fjord sediment.

Table 9.3 shows the total input to six of the fjords, which form part of the Danish inner marine waters. Transport out of the fjords is also shown. The catchment area of these six fjords is 14,100 km^2 or 47% of the total catchment area feeding the inner marine waters (29,907 km^2). These fjords alone have reduced nutrient inputs to the open waters of Kattegat and the Belt Sea by approx. 11,800 tonnes N and 176 tonnes P in 2003 (Table 9.3).

Fjords thus retain a significant proportion of the nitrogen input to Danish marine waters via riverine runoff and direct discharges since the total input to the inner marine waters amounted to 34,200 tonnes N and 1,171 tonnes P in 2003 (Table 9.2).

Together these six fjords retained 48% of their total nitrogen input in 2003, but only 17% of their total phosphorus input (Table 9.3). Only Limfjorden and Roskilde Fjord retained phosphorus, whereas there was net release of phosphorus from the other fjords. In some years, when these fjords reach a new equilibrium with the new lower level of phosphorus input, they will also exhibit net retention of phosphorus.

AQUATIC ENVIRONMENT 2004 – Figure 9.3

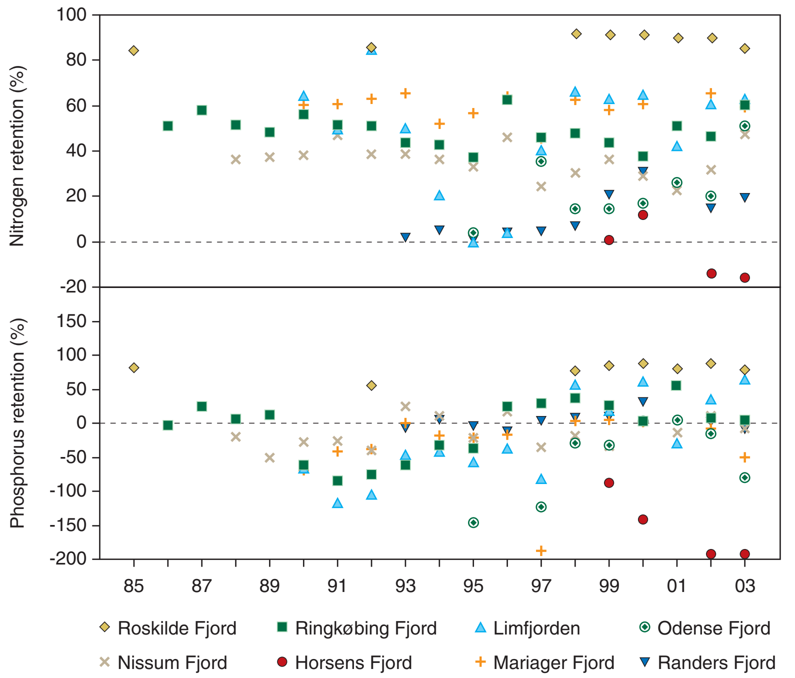


Figure 9.3 Proportion of nitrogen and phosphorus input retained in fjords over the period 1985–2003 (*Ærtebjerg et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Table 9.3

Total nitrogen		Total phosphorus	
Input (tonnes/yr)	**Export (tonnes/yr)**	**Input (tonnes/yr)**	**Export (tonnes/yr)**
24,800	13,000	1,017	841

Table 9.3 Combined mass balance for nitrogen and phosphorus in 2003 for the six fjords adjoining the Danish inner marine waters. The data for Limfjorden include the input from the North Sea (*Ærtebjerg et al., 2004*).

Trend in transport of nitrogen and phosphorus out of the fjords

The trend in the amount of nitrogen and phosphorus flowing from the eight fjords out into the open marine waters over the period 1989–2003 is shown in Figure 9.4. The calculated exports have been corrected for interannual differences in freshwater runoff to the fjords. In order to be able to compare the trend in the fjords the export has been normalized such that mean export for each fjord for the whole period is set to 0 and the deviation around the values for annual export is set to 1. With both nitrogen and phosphorus there is a clear trend towards decreasing export from the fjords. The reduction in inputs to the fjords has thus resulted in a reduction in the amounts that are transported out to the open sea.

AQUATIC ENVIRONMENT 2004 – Figure 9.4

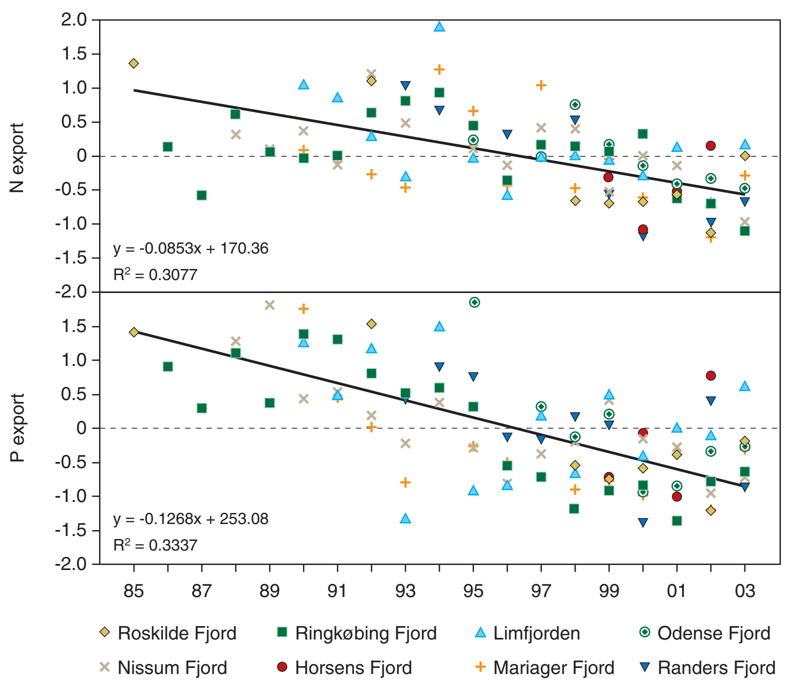


Figure 9.4 Runoff-corrected, normalized nitrogen and phosphorus export in eight Danish fjords over the period 1985–2003 (*Ærtebjerg et al., 2004*).

9.3 Nitrogen and phosphorus in seawater

Concentration levels in 2003

The concentrations of nitrogen and phosphorus are generally highest where a large proportion of the water is freshwater, for example in the inner parts of fjords with large inputs of freshwater. The individual localities also exhibit great seasonal variation, with the concentrations being lowest in summer, because the vegetation has taken up nutrients from the water and because input from the land is greatest in winter. In the open marine waters the nutrient concentration is lower and the geographic differences in concentration levels are less than in the fjords/coastal waters.

In general, the nitrogen and phosphorus concentrations in 2003 were the lowest or the next-lowest recorded since the monitoring programme began. This applies both to the content of total N and total P and to the content of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), which are immediately available for plant growth.

Winter concentrations (mean of the measured concentrations in January and February) of dissolved inorganic nitrogen and dissolved inorganic phosphorus are shown in Figures 9.5 and 9.6. These concentration levels are important because they usually determine the amount of algae that can form during the spring when there is sufficient light for algal growth.

The concentration of dissolved inorganic nitrogen (Figure 9.5) was up to approx. 2 mg N/l in the closed fjords (Odense, Mariager and Ringkøbing Fjords) and was generally under 0.1 mg N/l in the open marine waters. However, the concentration was considerably higher in the North Sea along the western coast of Jutland as the Jutland Current transports nutrients up along the coast from the large rivers Elbe, Weser and Rhine discharging into the North Sea or the English Channel. The lowest nitrogen concentrations were found in the Baltic Sea.

The geographic distribution of dissolved inorganic phosphorus (Figure 9.6) to some extent follows that of dissolved inorganic nitrogen, but the differences in concentration levels are not as great as for nitrogen. This is partly attributable to differences in the inputs (phosphorus inputs have decreased relatively more than nitrogen inputs) and partly to the fact that the sediments in the marine areas are oxic in winter and will therefore bind phosphorus from the water subsequently to release phosphorus into the water later in the year when the temperature is higher and the oxygen conditions in the sediment are poorer. Winter values for dissolved inorganic phosphorus are consequently less well suited for characterizing the potential for algal growth in the subsequent growth season than winter values for dissolved inorganic nitrogen.

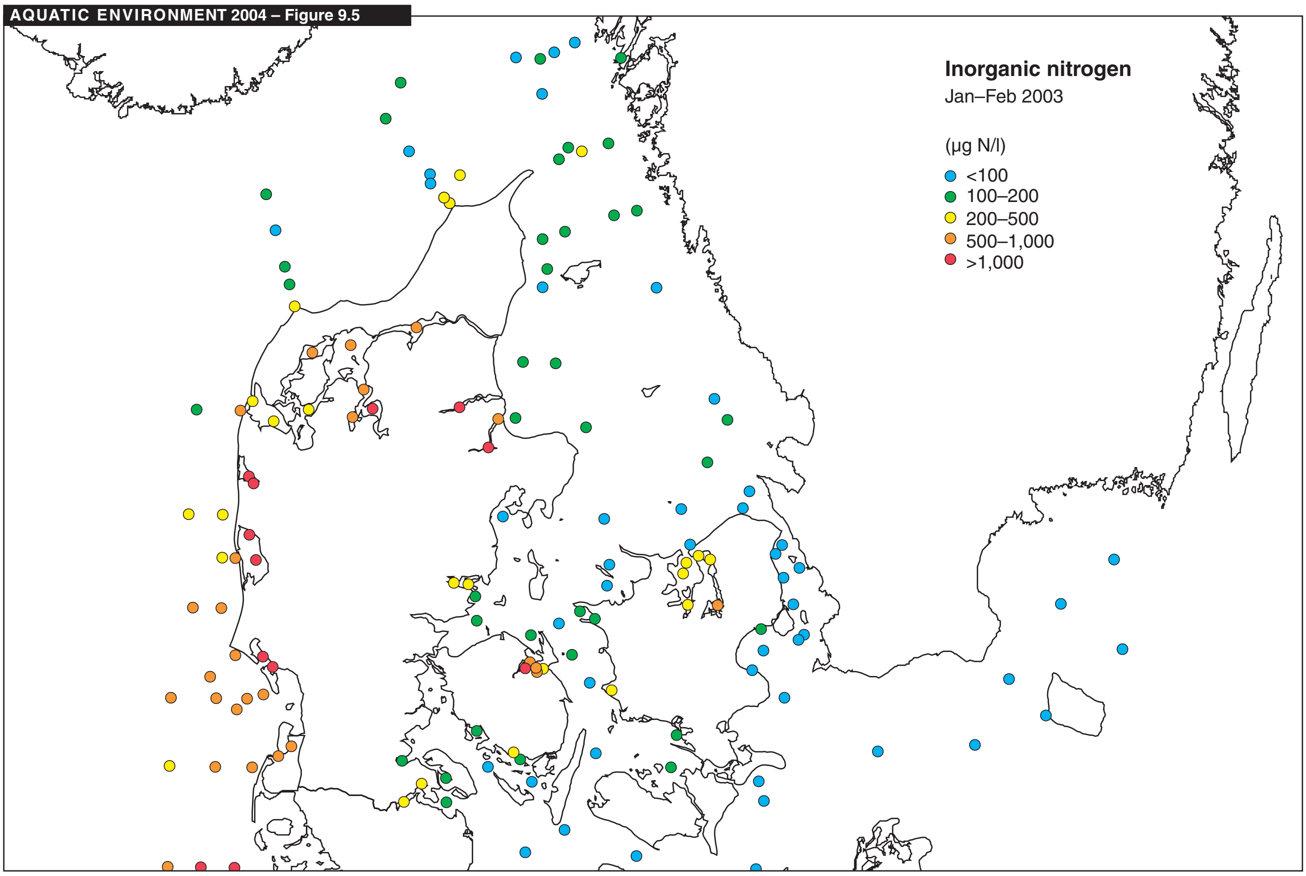


Figure 9.5 Winter mean concentrations (Jan–Feb) of inorganic nitrogen (DIN) in the surface water of Danish marine waters in 2003 (based on data from *Ærtebjerg et al., 2004* and *SMHI, Sweden*).

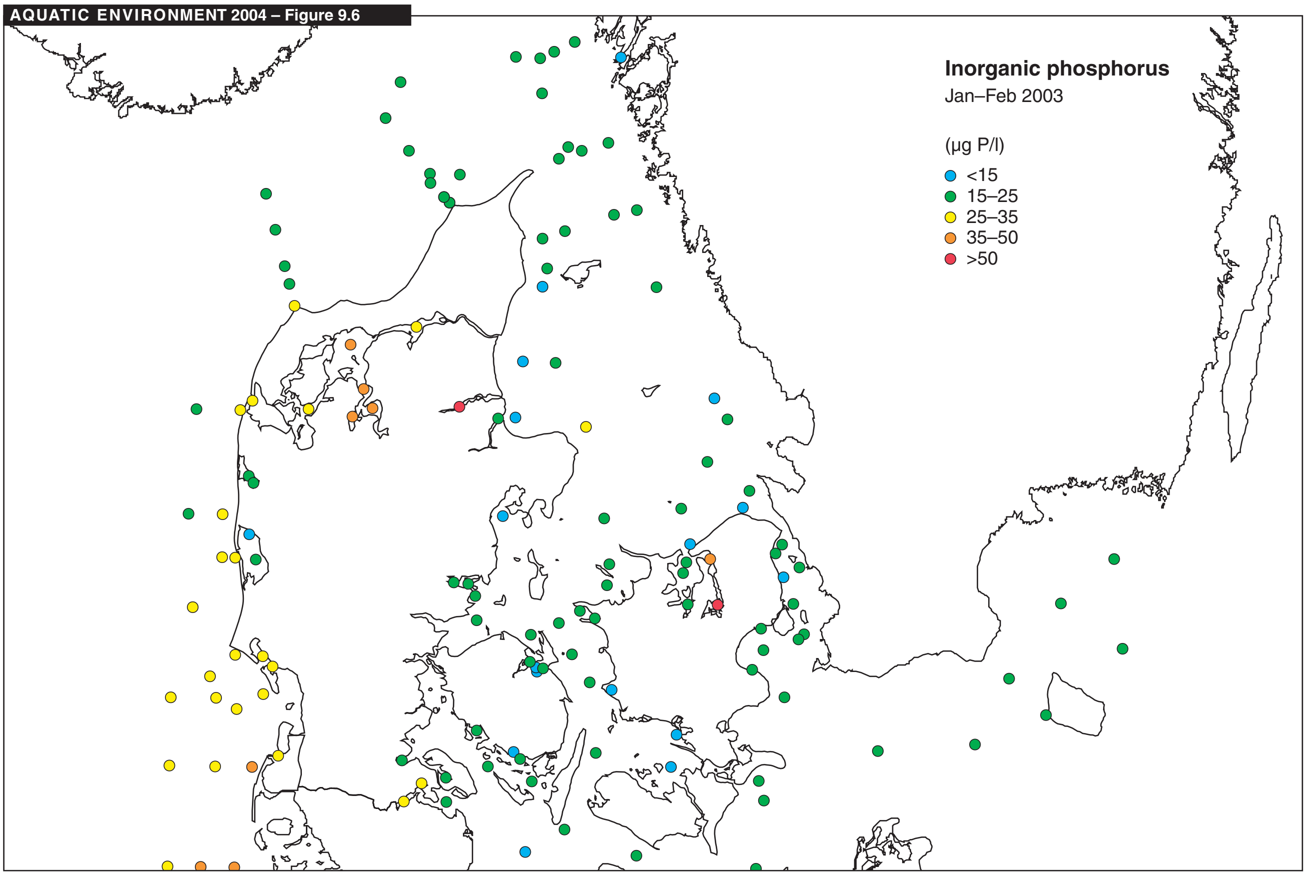


Figure 9.6 Winter mean concentrations (Jan–Feb) of inorganic phosphorus (DIP) in the surface water of Danish marine waters in 2003 (based on data from *Ærtebjerg et al., 2004* and *SMHI, Sweden*).

Trend in concentration levels

The trends in nitrogen and phosphorus concentrations in fjords/coastal waters and in open marine waters are shown in Figure 9.7 as the mean of the individual annual mean concentrations.

The nitrogen concentration in fjords/coastal waters has decreased considerably since the mid 1990s, most clearly in the case of DIN, which mainly reflects the nitrate concentration. The concentration of total N has also decreased, but to a lesser extent. The concentration levels in the open marine waters have been decreasing since the mid 1990s such that the general level of the annual mean concentration is now around 10 µg N/l for DIN and 250 µg N/l for total N (Figure 9.7).

In fjords/coastal waters the phosphorus concentration (both total P and DIP) halved up to the end of the 1990s, the mean concentration of DIP now being around 10 µg P/l and that of total P being around 40 µg P/l. The phosphorus concentrations are also lower in the open marine waters and seem to have stabilized at a DIP concentration of around 5 µg P/l and a total P concentration of around 20 µg P/l (Figure 9.7).

The interannual variation seen in Figure 9.7 is partly attributable to the greater input of nutrients from the land and air in wet years than in dry years (compare with Figure 9.2). If the values in Figure 9.7 are corrected for interannual differences in freshwater runoff, the trend over the period is smoother (see *Ærtebjerg et al., 2004*).

The measured reductions in nutrient concentrations are largely due to the Danish efforts to improve wastewater treatment and reduce leaching from cultivated land. Corresponding initiatives to reduce nutrient discharges in neighbouring countries might have contributed to the lower concentrations in the open marine waters.

AQUATIC ENVIRONMENT 2004 – Figure 9.7

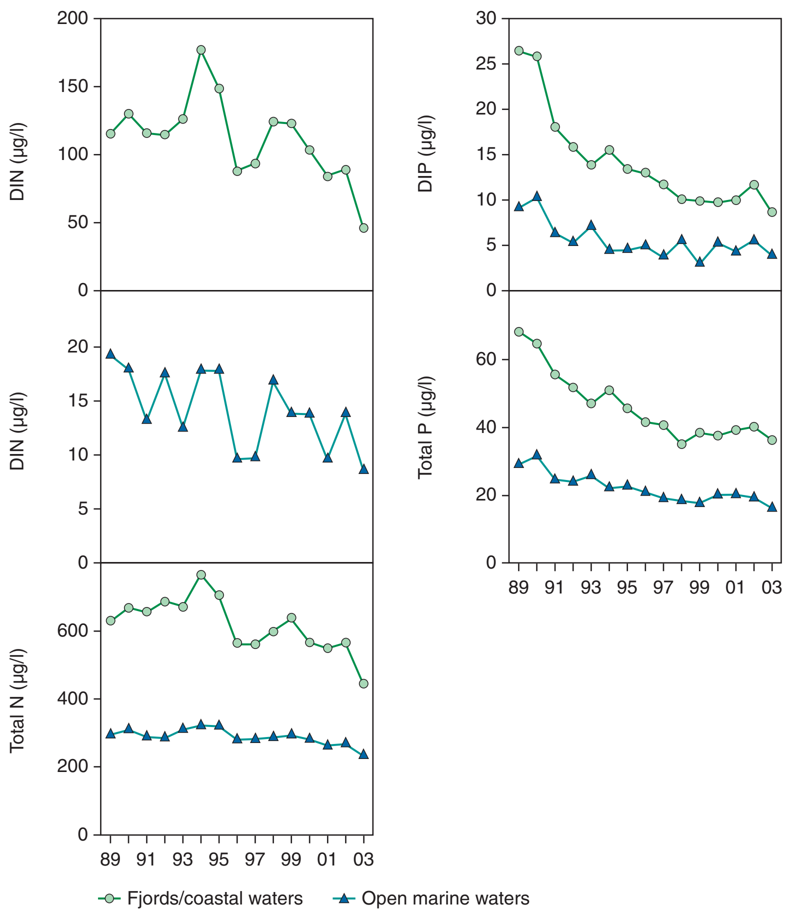


Figure 9.7 Annual mean concentrations of dissolved inorganic nitrogen (DIN), total nitrogen (Total N), dissolved inorganic phosphorus (DIP) and total phosphorus (Total P) in the surface water of fjords/coastal waters and open marine waters over the period 1989–2003 (*Ærtebjerg et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 9.8

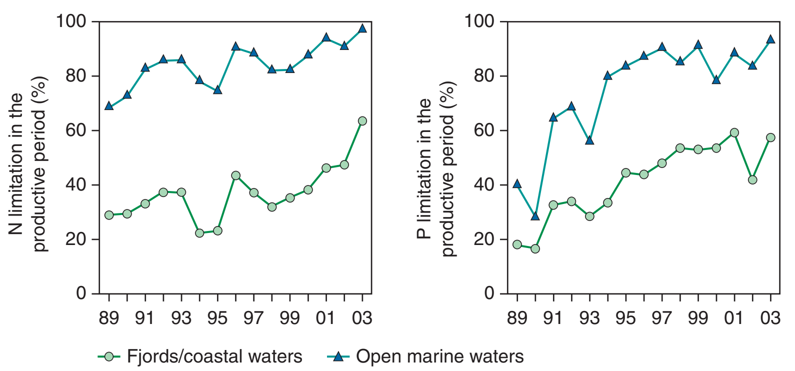


Figure 9.8 Trend in potential nitrogen (N) and phosphorus (P) limitation of algal growth in fjords/coastal waters and open marine waters. The percentages are calculated as the probability that the concentration will fall below 28 µg N/l and 6.2 µg P/l, respectively (*Ærtebjerg et al., 2004*).

Trend in nutrient limitation of algal growth

As a consequence of the trend towards decreasing DIP concentrations at the beginning of the 1990s followed by stabilization and decreasing DIN concentrations in recent years, phosphorus has become potentially more limiting since around 1990 and nitrogen since around 1998 (Figure 9.8). Thus both nutrients are now potentially limiting in more than 50% of the productive period (March–September) calculated as the mean value for all fjord and coastal water stations encompassed by the Danish Aquatic Monitoring and Assessment Programme, NOVA-2003.

9.4 Phytoplankton

Phytoplankton are the microscopic algae freely suspended in the water. Diatoms and dinoflagellates are the dominant algal groups in most Danish fjords and the most important algal groups in the open marine waters. Diatoms that sink from the surface water supply the benthic invertebrates with considerable amounts of organic matter. Phytoplankton production is a cornerstone of the marine food chain. If phytoplankton production becomes too high, however, so much organic matter can sink to the seafloor that oxygen consumption there results in oxygen deficit.

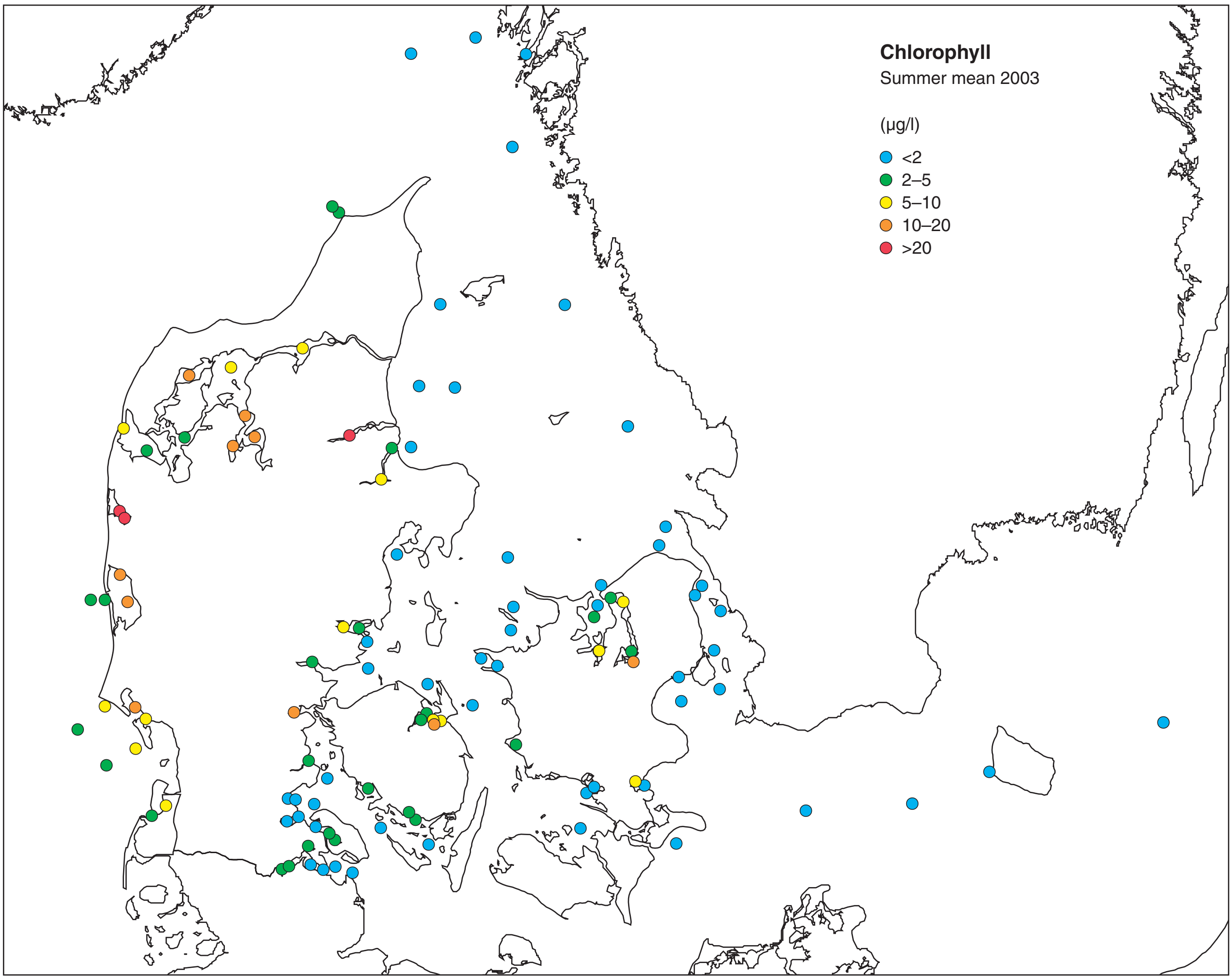
2003

The development of algal biomass in 2003 was roughly normal in the Danish marine waters. Algal biomass during the spring bloom was generally greater than normal, while summer algal production and algal biomass were lower than normal in most areas, and Secchi depth during summer was greater than normal.

Algal biomass is greatest in areas with the highest nutrient concentrations (the fjords) and lowest in the open marine waters. The mean surface water chlorophyll concentrations in May–September 2003 are shown in Figure 9.9 as a measure of algal biomass. The mean chlorophyll concentration levels reach more than 10 µg/l in the most eutrophic fjords and are around 1 µg/l in open marine waters lacking in significant "local" nutrient sources. In the Jutland Current along the western coast of Jutland the concentration is higher than in the Baltic Sea and the Kattegat.

Secchi depth (Figure 9.10) reflects algal biomass and the amount of dissolved organic matter in the water. In shallow waters, however, it can be reduced by resuspended sediment. The clearest water measured was at Bornholm, where the mean summer Secchi depth was 12.5 m. In the open parts of the Kattegat and the Belt Sea, Secchi depth was 8 m. Along the southern part of the North Sea coast of Jutland it was somewhat lower. Secchi depth was lowest in the shallow fjords that receive large amounts of freshwater runoff and in the Wadden Sea.

AQUATIC ENVIRONMENT 2004 – Figure 9.9



Figur 9.9 Algal biomass in the surface water of Danish marine waters in 2003 illustrated by the mean of the measured concentrations of chlorophyll in the water in May–September 2003 (based on data from *Ærtebjerg et al., 2004* and *SMHI, Sweden*).

Trend in Secchi depth, algal biomass and algal production

The trend in these quality parameters is illustrated by an index value for each parameter for each year (*Ærtebjerg et al., 2004*).

The changes in Secchi depth, algal biomass and algal production are not generally as great as those in the concentration of nutrients in the water, and the index values exhibit considerable interannual variation. This is due to the fact that algal biomass is not solely regulated by nutrient availability, but also by factors such as solar radiation, grazing by fauna in the water and in shallow waters by benthic filter feeders, and wind-induced mixing of the water column. In addition, the biological systems may exhibit some resilience towards adaptation to reduced nutrient concentrations.

The trend in the index values over the period 1978–2003 is shown for fjords, the Belt Sea and the Kattegat in Figure 9.11.

In the fjords, overall state improved over the period 1989–1993 and has since been stable. This trend is attributable to the reduction in inputs of phosphorus from point sources, which mainly took place between 1987 and 1993. There is a tendency towards improvement from 1993 onwards, especially for chlorophyll, but this is not statistically significant at the 5% level. The index value for algal production is tending to decrease, but the value has been higher again over the past three years. Secchi depth exhibits a weak tendency towards an increase over the period.

In the Belt Sea the trends are roughly the same as in the fjords. Here it is particularly obvious that the index values for Secchi depth and chlorophyll seem to have changed in a positive direction in recent years, while the index value for algal production has been high (Figure 9.11). This can be due to a change in the method used to measure algal production, however.

In the Kattegat the trends resemble those in the Belt Sea, but the index values have generally improved less than in the fjords and the Belt Sea because the Kattegat is less affected by direct inputs from the land than fjords and the Belt Sea.

AQUATIC ENVIRONMENT 2004 – Figure 9.10

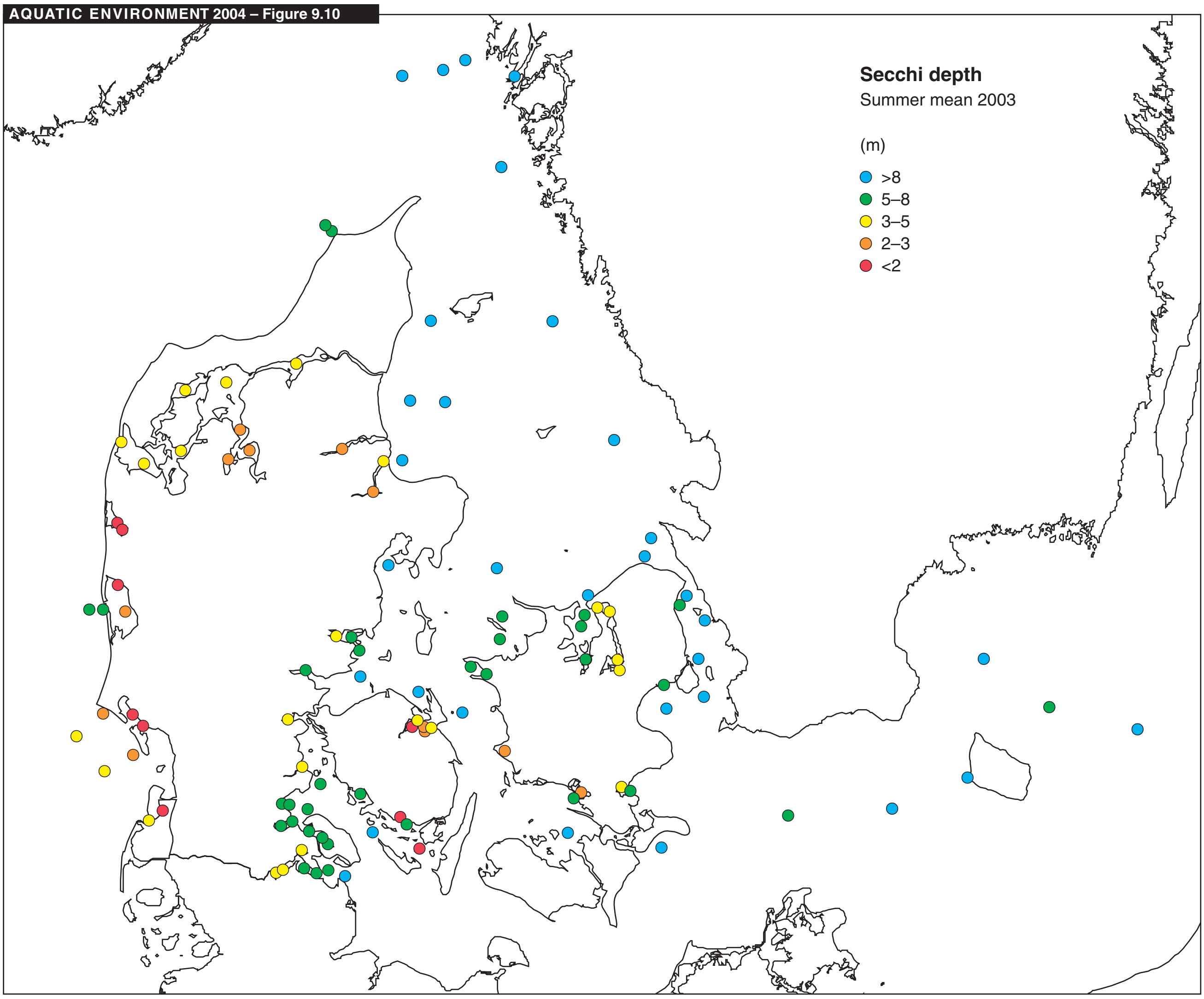


Figure 9.10 Secchi depth in Danish marine waters in 2003 illustrated by the mean of the measurements made in May–September 2003 (based on data from *Ærtebjerg et al., 2004* and *SMHI, Sweden*).

From the index value curves for Secchi depth, chlorophyll and algal production shown in Figure 9.11 it can be seen that the natural interannual variation in these quality parameters is so great that it is only possible to identify biological changes in the water bodies through long time series of measurements. Removal of a large part of the natural variation with the help of modelling reveals a 2.3%/yr decrease in chlorophyll concentration over the period 1989–2003 in the Belt Sea and a 2.0%/yr decrease in the Kattegat. Correspondingly, Secchi depth increased by 1.6%/yr in the Belt Sea and 0.6%/yr in the Kattegat.

9.5 Oxygen conditions

Oxygen deficit is a particularly great problem in Danish marine waters because the water column is often stratified with surface water with a low salinity and with heavier, saltier bottom water. This reduces the possibility for exchange/oxygenation of the bottom water. Oxygen deficit impoverishes habitat conditions for benthic invertebrates and fish. The reduction in oxygen concentration at the bottom and the possible development of oxygen deficit is a secondary effect of eutrophication. Enhanced nutrient input leads to enhanced primary production, which results in more organic matter being deposited on the seafloor and hence to enhanced oxygen consumption. The actual oxygen concentration does not correlate directly with the nutrient input, however, as the oxygen concentration is a result of both oxygen consumption and oxygen input, with the latter depending of the meteorological conditions, especially wind strength and direction.

AQUATIC ENVIRONMENT 2004 – Figure 9.11

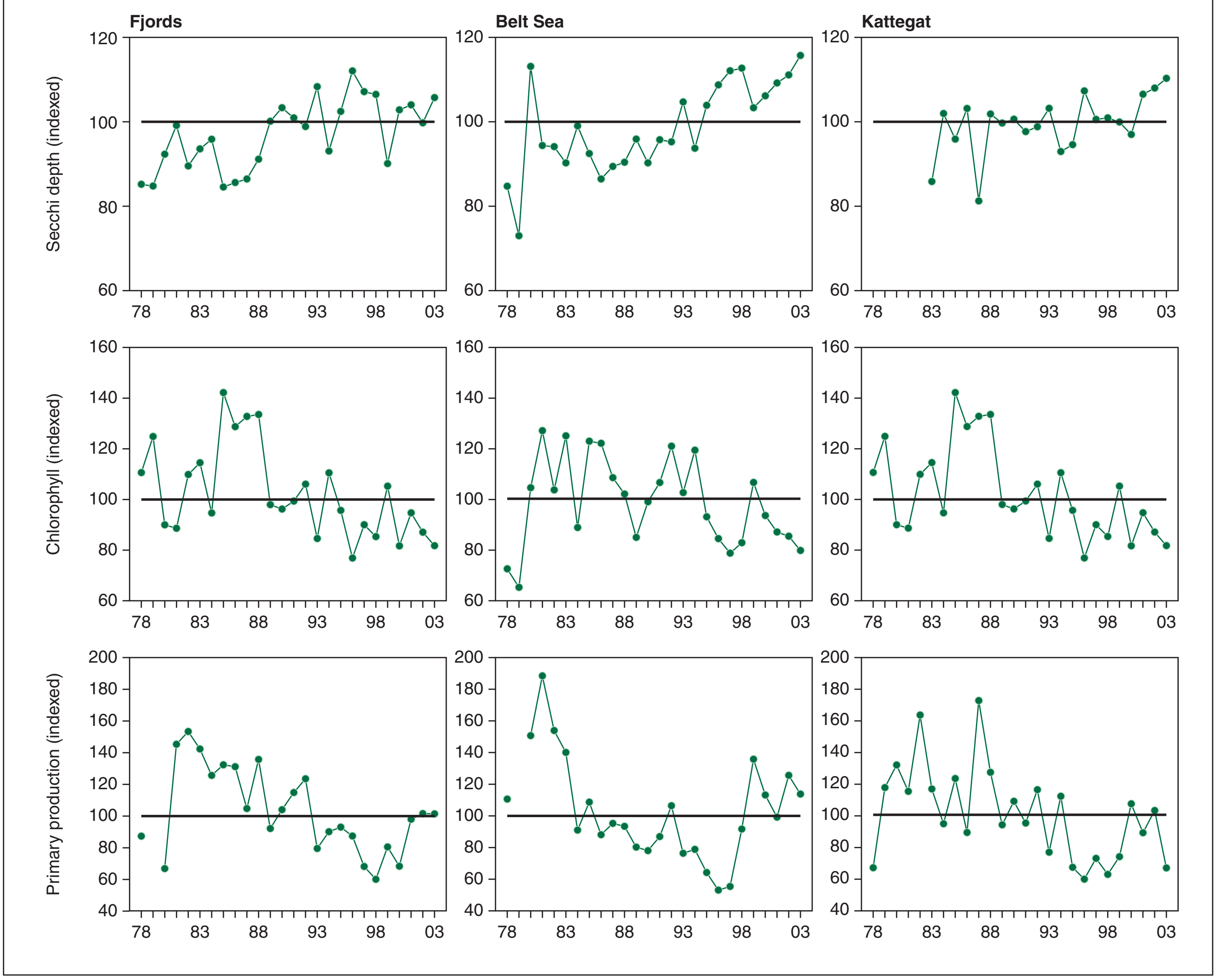


Figure 9.11 Indexed trends in Secchi depth, chlorophyll and algal production (primary production) in fjords, the Belt Sea and the Kattegat over the period 1978–2003 (*Ærtebjerg et al., 2004*).

Oxygen deficit in 2003

Episodes of oxygen deficit and severe oxygen deficit were less widespread and more short-lasting in 2003 than during the major oxygen deficit in 2002. The oxygen deficit in 2003 was particularly widespread in the Belt Sea and the southern Kattegat, with the most severe and long-lasting oxygen deficit located in the southern Little Belt Sea and Flensburg Fjord.

The oxygen deficit in 2003 was more widespread than could be expected based on the low nutrient inputs and concentrations and the generally low algal biomass, however. The oxygen concentration in the bottom water in the inner marine waters was thus also high until June, but decreased to less than normal in September, when widespread oxygen deficit occurred (Figure 9.12) and remained below normal for the rest of the year.

The main reason for this trend in oxygen concentration is probably the lack of windy weather during the whole period July–November 2003 and hence the lack of oxygen input to the bottom water. However, the after-effects of the extreme oxygen deficit in autumn 2002 have probably enhanced the oxygen deficit in 2003. During severe, long-lasting episodes of oxygen deficit an "oxygen debt" builds up in the form of reduced compounds in the sediment that do not manage to be reoxidized during the winter before deposition of algae the following spring once again raises oxygen consumption. Sediment chemistry investigations in spring 2003 in fact revealed that the sediments in many coastal waters had not been re-oxidized to the normal extent during the winter. As a consequence, oxygen consumption in the sediment becomes greater than normal the following summer and autumn.

The absence of benthic invertebrates further delays reoxidation of the sediments. In autumn 2002, the benthic invertebrate fauna was severely reduced in an area totalling at least 3,400 km^2 in the Belt Sea and the fjords of eastern and southern Jutland due to oxygen deficit. When there are fewer or no benthic invertebrates to mix the sediment and pump oxygenated water down into it, oxygenation of the reduced compounds in the sediment is delayed.

AQUATIC ENVIRONMENT 2004 – Figure 9.12

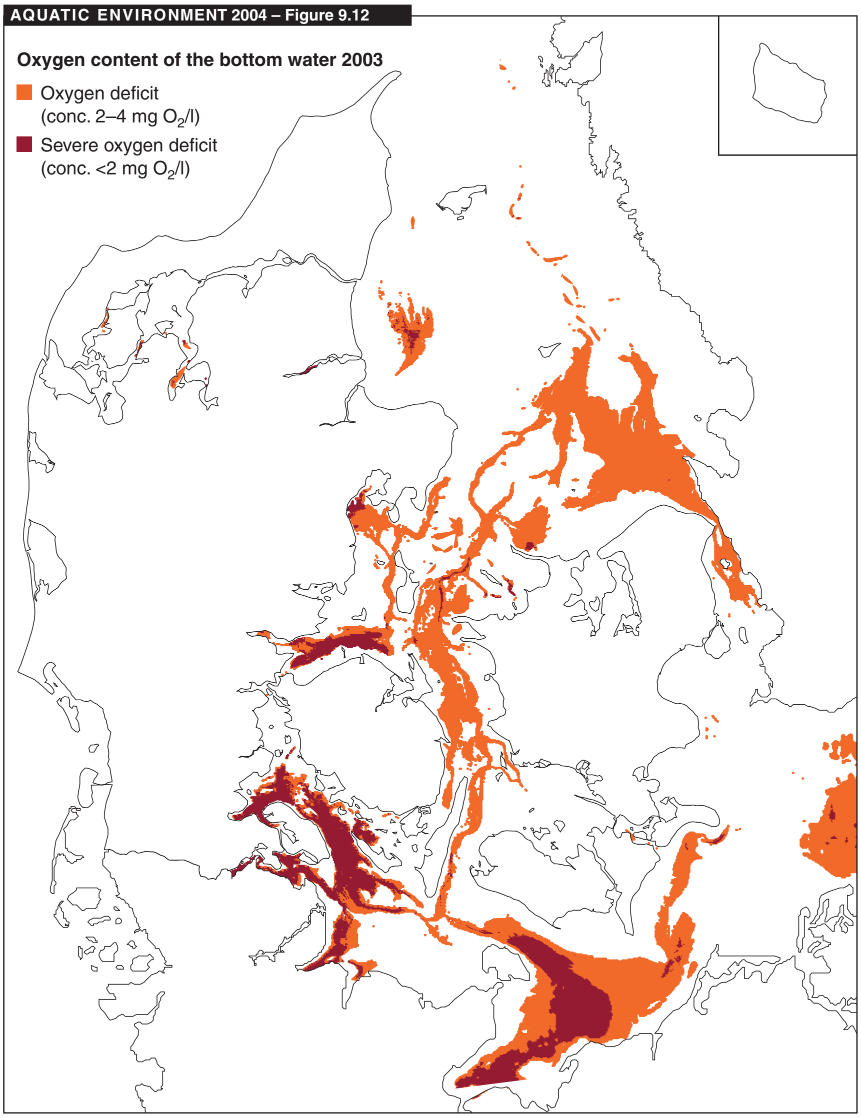


Figure 9.12 The extent of oxygen deficit in the Danish inner marine waters in 2003 was greatest on 15–21 September. At that time oxygen deficit covered an area of approx. 10,000 km^2, while severe oxygen deficit covered an area of approx. 2,200 km^2 (the Arkona Sea is not included) (*Ærtebjerg et al., 2004*).

9.6 Submerged aquatic vegetation

Eelgrass

The eelgrass stands are important nursery areas for invertebrates and fish. Eelgrass is utilized as a biological indicator of environmental quality in marine waters, among other reasons because its maximum depth distribution reflects Secchi depth at the location over an extended period.

The maximum depth distribution of eelgrass over the period 1989–2003 was greatest along the open coasts (4.7–6.2 m), a little less in the outer fjords (3.2–4.2 m) and least in the inner fjords (2.6–3.5 m).

No clear trend in eelgrass maximum depth distribution was detectable over the period 1989–2003 as a whole in the open coastal waters. The maximum depth distribution varied considerably during the period, however, with the eelgrass occurring at great depths from 1989 to 1991, at reduced depths from 1992 to 1996, and again at great depths from 1997 onwards (Figure 9.13).

In the fjords the maximum depth distribution of eelgrass decreased over the period as a whole, both in the outer and the inner parts of the fjords. At the same time, coverage also decreased. Given the decreasing nutrient concentrations in the fjords and the indication

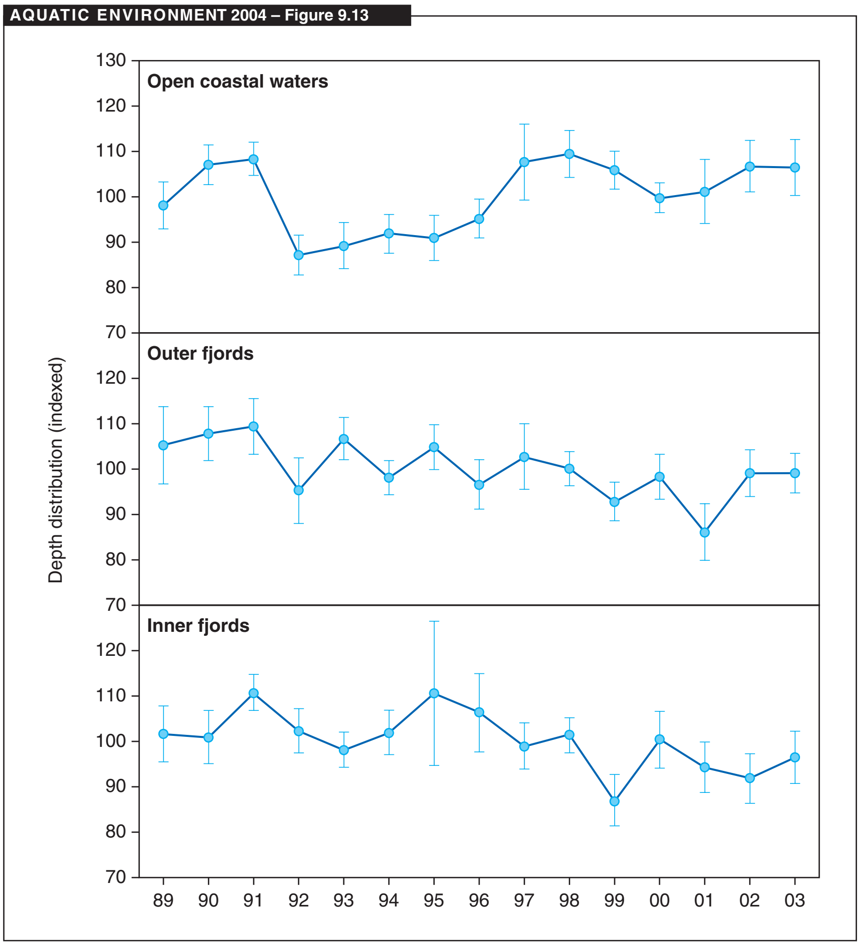


Figure 9.13 Indexed trend in eelgrass maximum depth distribution over the monitoring period 1989–2003 shown for open coastal waters, outer fjords and inner fjords (*Ærtebjerg et al., 2004*).

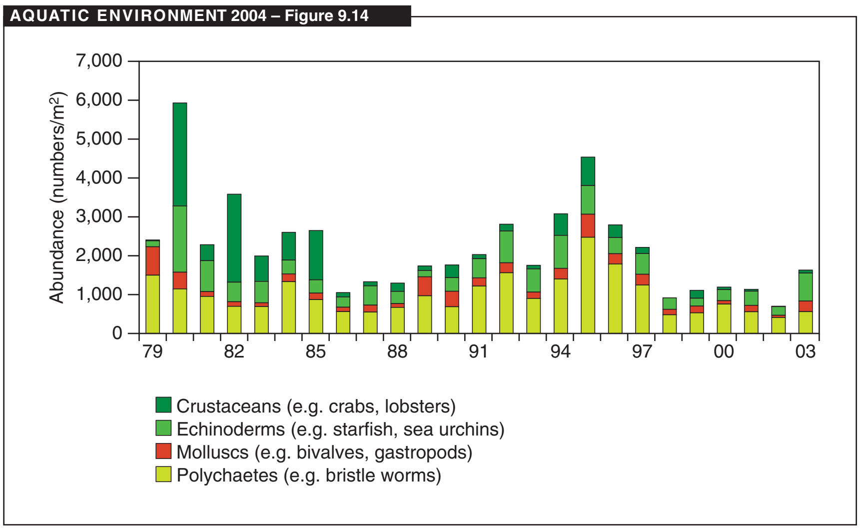


Figure 9.14 Trend in the total abundance of the main groups of benthic invertebrates at three HELCOM stations in Danish inner marine waters (*Ærtebjerg et al., 2004*).

of reductions in algal biomass in the water, the eelgrass populations could be expected to increase. A possible explanation as to why this has not been the case could be the occurrence of oxygen deficit (*Ærtebjerg et al., 2004*).

Eutrophication-dependent algae

Many large annual algae (e.g. sea lettuce and other large green algae) are favoured when nutrient inputs are high, and high coverage by such algae therefore indicates nutrient loading.

Coverage by eutrophication-dependent algae did not exhibit any clear trend over the period 1989–2003. Only coverage at a depth of 1–2 m in the inner fjords exhibited a significant decrease over the period.

9.7 Benthic invertebrates

The population size and composition of the marine benthic invertebrate community is the combined result of numerous natural and anthropogenic factors. Eutrophication affects the benthic fauna through enhanced input of organic matter (food), but can also enhance the frequency of oxygen deficit. To what extent a reduction is attributable to reduced input of food or is due to oxygen deficit can only be determined if the pressures have been quantified for the individual water bodies.

In the Kattegat and the Belt Sea, total benthic invertebrate abundance has varied over the past 25 years and was high at the beginning of the 1980s and mid 1990s followed by a marked decrease (Figure 9.14). In 2003, abundance was higher than during the five preceding years, however, and hence breaks the pattern of a decrease in abundance seen in the preceding years. The increase is primarily accounted for by echinoderms (starfish, sea potato, etc.) and molluscs.

Overall, total benthic invertebrate abundance, biomass and species number have neither increased nor decreased in the fjords and coastal waters over the period 1998–2003 (Table 9.4). In order to give an impression of the species diversity at various localities, Table 9.4 summarizes the mean number of benthic invertebrate species found at each individual monitoring station each year over the period 1998–2003.

At many localities there was a marked change from 2002 to 2003, with the magnitude of the change being closely correlated to the occurrence of oxygen deficit the year before. In the areas that were not affected by oxygen deficit in 2002 the communities thus did not differ from those in the previous years. In the areas affected by oxygen deficit in 2002, however, a change had occurred. The magnitude of this change depended on the severity and duration of the oxygen deficit and was greatest in areas with protracted oxygen deficit of <2 mg/l. The most severely affected areas were the northern part of the Little Belt, Vejle Fjord, Skive Fjord, Karrebæksminde Bay and parts of Hevring Bay and the southern Belt Sea. The loss of benthic invertebrates due to oxygen deficit in 2002 is calculated to be around 370,000 tonnes (wet weight).

In 2003, the benthic invertebrates lost in 2002 were to some extent replaced by new individuals with a different species composition. In several of the areas where the fauna had been completely or partially eradicated, the newly established community was dominated by the bivalve *Abra albra*, for example in Karrebæksminde Bay. In the southern Little Belt, where the fauna was almost completely eradicated, recolonization also occurred during the course of 2003. These populations were eradicated again by oxygen deficit in autumn 2003, however.

AQUATIC ENVIRONMENT 2004 – Table 9.4

BENTHIC FAUNA 1998–2003	No. of species					
Name of water body	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Roskilde Fjord	29	29	23	30	30	27
Horsens Fjord	-	24	24	40	46	29
Vejle Fjord	-	52	36	55	47	35
Kolding Fjord	-	57	36	61	58	43
Ringkøbing Fjord	20	22	22	17	15	21
Nissum Fjord	30	29	33	28	27	28
Hevring Bay	76	69	87	91	95	55
Øresund	68	51	54	52	30	52
Køge Bay	26	30	28	35	34	24
Odense Fjord	66	78	57	57	56	65
Ringgårdbassin	27	28	25	19	17	12
Roskilde Fjord	33	30	31	37	33	29
Isefjord	24	36	19	15	17	33
Kattegat	63	51	61	66	59	68
Little Belt	35	50	51	27	61	28
Karrebæksminde Bay	40	28	37	31	38	42
Skive Fjord	31	36	24	41	46	30
Nissum Broads	33	31	49	34	41	58
Løgstør Broads	42	34	32	35	36	29
Wadden Sea (N)	43	43	41	47	42	33
Aarhus Bay	62	46	54	57	33	64
Mariager Fjord	17	14	28	26	21	24
Flensborg Fjord	-	30	30	17	24	15
Wadden Sea (S)	41	36	43	40	42	43
Nivå Bay	-	62	65	57	62	73
Mean	**40**	**40**	**40**	**41**	**40**	**38**

Table 9.4 Number of benthic invertebrate species found in the individual coastal waters over the period 1998–2003 shown together with the total mean. The blue shading indicates that the number of species is high, and red that it is low (*Ærtebjerg et al., 2004*).

Quality objective compliance

The general objective for the marine waters (*Danish EPA, 1983*) is that the natural flora and fauna may not be more than slightly affected by pollutant inputs. The objective for coastal waters is specified in the County Regional Plans.

In 2003, the majority of marine waters failed to comply with their current environmental quality objective. Moreover, despite certain improvements, there has not been any major change in the degree of quality objective compliance since 1989.

The quality objective is generally considered to be fulfilled in the open parts of the North Sea and the Skagerrak.

In the coastal parts of the Skagerrak and in the open northern and central parts of the Kattegat, the quality objective is considered close to being met.

In the other Danish marine waters the quality objective has not yet been met, primarily because the high nutrient inputs have considerably enhanced the amount of phytoplankton and eutrophication-dependent macroalgae. In addition, these changes have led to the shading-out of perennial submerged macrophytes and unnaturally frequent and severe episodes of oxygen deficit.

In fjords and coastal waters the lack of quality objective compliance is attributable to the occurrence of hazardous substances, especially TBT, PAH and certain heavy metals.

Compliance with the quality objective necessitates a further reduction in nutrient inputs and in some cases, also of inputs of hazardous substances.

10 Heavy metals

Heavy metals and other inorganic trace elements occur naturally in the environment in relatively small amounts. Their properties differ considerably. Some have harmful effects at even low concentrations. Others are necessary for the human organism in small amounts, but are harmful to health and the environment in larger amounts. Some metals, including cadmium and mercury, accumulate up the food chain. Human activities can lead to the occurrence of these substances in elevated concentrations, for example through the discharge of wastewater.

The monitoring of heavy metals in 2003 encompassed point sources, the atmosphere, groundwater and mussels/clams, fish and sediment in marine waters. The comprehensiveness of the metal analyses varies in the individual elements of the monitoring programme, although cadmium, lead, nickel, zinc and copper are included in all elements.

10.1 Atmospheric deposition

Atmospheric deposition of heavy metals is a major source of their occurrence in the environment. The atmospheric deposition of these substances is quantified by measuring their concentration in the air and wet deposition.

Wet deposition of heavy metals in 2003 did not differ significantly from that in the last few years. Over a longer perspective, though, a clear reduction is apparent in both the atmospheric concentration and wet deposition of the metals encompassed by the monitoring programme (see for example lead and zinc in Figure 10.1).

The interannual variation in wet deposition of a heavy metal depends on several factors, the most important of which is the level of emissions to air in the areas that contribute to atmospheric deposition of metals on Denmark. Wind and weather conditions are other factors that can significantly affect both atmospheric concentrations and deposition.

An overall evaluation of the available information about emissions of heavy metals from sources in Eastern and Western Europe and Denmark reveals a good correlation between the decrease in emissions and both the atmospheric concentrations and total deposition. This is illustrated for lead and zinc in Figure 10.2 by way of example.

10.2 Wastewater

The heavy metal content of effluent from wastewater treatment plants is largely the same as in previous investigations in 1994 and 1996. The content varies considerably, though, depending on what industries, etc. are connected to the individual treatment plants.

The concentrations of heavy metals in the effluent from the wastewater treatment plants are generally close to the

AQUATIC ENVIRONMENT 2004 – Figure 10.1

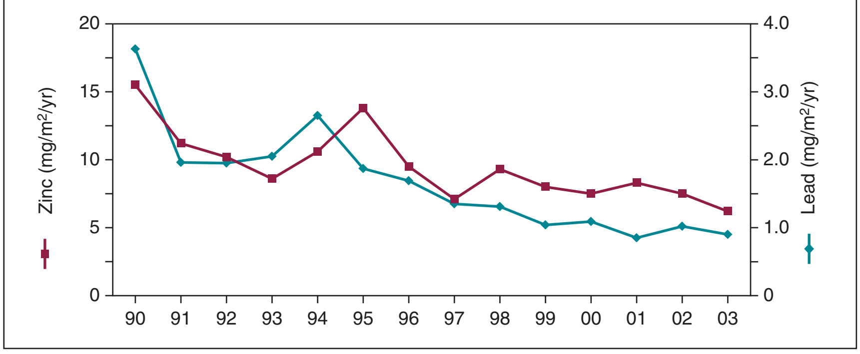
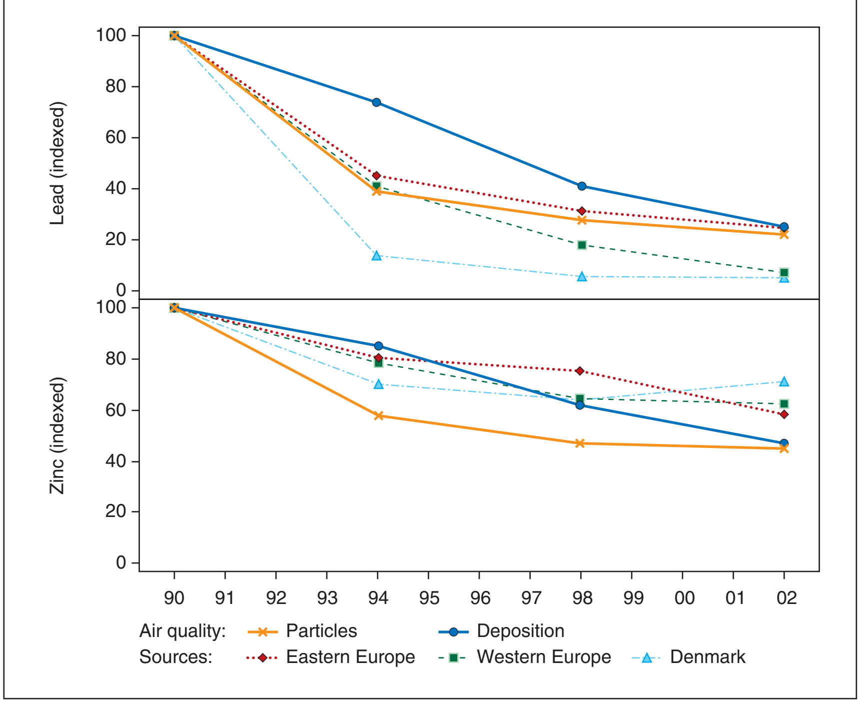


Figure 10.1 Trend in wet deposition of lead (Pb) and zinc (Zn) over the period 1990–2003 (*Ellermann et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 10.2



Figur 10.2 Indexed lead and zinc wet deposition and particle concentrations in the air compared with emissions from countries in Eastern Europe, Western Europe and Denmark based on the mean values for the three-year period around the years shown with 1990 set at 100 (*Ellermann et al., 2004*).

quality criteria set for surface waters (Table 10.1). At five plants, however, the measured concentrations of copper were five-fold greater than the quality criterion. In the case of zinc, there is a single plant where the measured concentration was ten-fold greater than the quality criterion. The Danish EPA's general assessment is that the concentrations measured in effluent from wastewater treatment plants do not present any major problem in relation to the quality criteria for the aquatic environment. In assessing compliance with the quality criteria, account is taken of the initial dilution that takes place immediately after discharge.

10.3 Groundwater

The groundwater is analysed for heavy metals and a number of other trace elements that are together termed inorganic trace elements. The inorganic trace elements occur naturally in the groundwater, but can also be present in elevated concentrations as a result of human activities.

Exceedances of the limit values for inorganic trace elements in drinking water are seen in both the near-surface groundwater monitored in the agricultural monitoring catchments and in the deeper groundwater monitored at the groundwater monitoring sites and as part of the waterworks well control (Table 10.2).

The groundwater in the agricultural monitoring catchments, where the filters are in the near-surface groundwater, clearly sticks out in that the limit values for lead, zinc and nickel are exceeded far more frequently than in the groundwater at the groundwater monitoring sites and the waterworks wells.

In the case of arsenic, the frequency of exceedances of the limit value for drinking water is considerably greater at the groundwater monitoring sites and in the waterworks wells than in the agricultural monitoring catchments due to the difference in the sampling depth. In the latest Statutory Order on Drinking Water, the limit value has been lowered from 50 µg/l to 5 µg/l (*Ministry of the Environment, 2001*). The presence of arsenic in the groundwater is due to the geological conditions in the aquifer. Exceedances of the limit value primarily occur in areas with tertiary marine clay in the ground or in areas where the passing ice has left tertiary marine clay mixed into the moraine layers. Younger marine deposits can also have a high arsenic content, though.

In waterworks incorporating water treatment and efficient sand filters the inorganic trace elements are to some extent retained. In such cases, exceedance of the limit values in the groundwater do not necessarily pose a problem as regards drinking water quality. In contrast, the trace elements can pose a problem for drinking water quality in individual water supplies or small waterworks without water treatment.

AQUATIC ENVIRONMENT 2004 – Table 10.1

	Effluent concentration (µg/l)			Quality criteria (S.O. 921) (µg/l)*	
	Mean	95% percentile	5% percentile	Fresh water	Sea water
Arsenic	1.3	5.3	0.0	4	4
Lead	1.9	5.3	0.3	3.2	5.6
Cadmium	0.09	0.5	0.0	5.0	2.5
Chromium	2.3	9.5	0.4	10	1.0
Copper	6.7	23	1.5	12**	2.9**
Mercury	0.09	0.3	0.0	1.0	0.3
Nickel	6.4	16	1.6	160	8.3
Zinc	91	252	24	110	86

*) The quality criteria for lead, chromium, copper, nickel and zinc are proposed quality criteria as quality assessment of the data has not yet been completed (*Ministry of Environment and Energy, 1996*).

**) The values for copper are upper limits. The Danish EPA has proposed adding a quality criterion for the background concentration of copper of 1 µg/l.

Table 10.1 Mean values and percentiles for heavy metal concentrations in the effluent from wastewater treatment plants in the period 1998–2003 shown together with the national quality criteria for water bodies (data from *Danish EPA, 2004*).

AQUATIC ENVIRONMENT 2004 – Table 10.2

% EXCEEDANCE OF LIMIT VALUE FOR DRINKING WATER	Limit value drinking water (µg/l)	Agricultural monitoring catchments		Groundwater monitoring sites		Waterworks wells	
		At least one analysis	All analyses	At least one analysis	All analyses	At least one analysis	All analyses
Arsenic	5	8%	0%	15%	5%	17%	3%
Lead	5	39%	0%	1%	<1%	<1%	0%
Nickel	20	56%	5%	6%	1%	4%	1%
Zinc	100	46%	8%	6%	1%	2%	0%

Table 10.2 Percentage of analysed filters in which the groundwater concentration of selected heavy metals exceeded the limit value for drinking water in groundwater monitoring sites and waterworks wells (1993–2003) and in agricultural monitoring catchments (1998–2003) (data from *GEUS, 2004*).

10.4 Marine waters

As in groundwater, heavy metals are naturally occurring in the marine environment. In addition, heavy metals are input to the marine environment from a number of sources, e.g. shipping, atmospheric deposition, wastewater and other runoff from the land. The content of heavy metals in mussels/clams and fish is used as a general indicator for heavy metal loading of the marine environment. In addition to mussels/clams and fish, monitoring of heavy metals in the marine environment in 2003 also encompassed sediment.

Heavy metals in mussels/clams

In most areas the levels of heavy metals in mussels/clams corresponded to the classification "lightly to moderately polluted" under the Norwegian classification system drawn up by the Norwegian Pollution Control Authority (*Norwegian Pollution Control Authority, 1997*).

The highest levels of lead, cadmium and mercury were detected in the Øresund, while the highest levels of nickel and copper were detected in Ringkøbing Fjord. The copper level in Ringkøbing Fjord corresponded to the classification "strongly polluted".

It should be noted, though, that the measurements in Ringkøbing Fjord were made on the soft-shelled clam, whereas the other measurements were made on the common mussel, and that this could influence interpretation of the data. The copper concentrations in common mussels from the Øresund, Randers Fjord and fjords on Funen corresponded to the classification "severely polluted" (Figure 10.3).

AQUATIC ENVIRONMENT 2004 – Figure 10.3

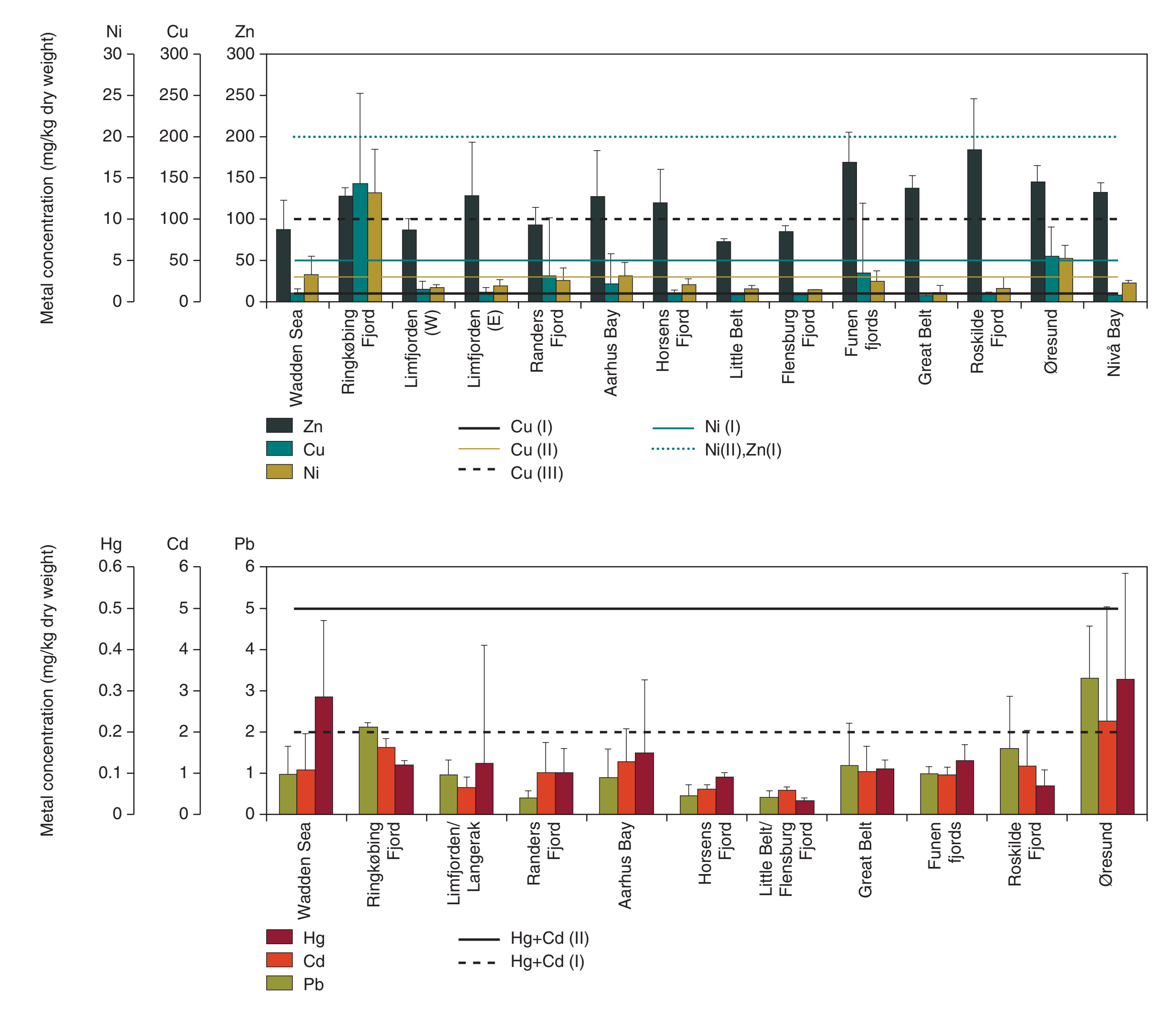


Figure 10.3 Metal concentrations (mg/kg dry matter) in mussels (mean and maximum of 1–5 stations per area with 1–3 replicates per station) from various Danish marine waters. The horizontal lines indicate the limit values for moderately (class I/II), strongly (II/III) and severely polluted (III/IV) pursuant to the classification used by the Norwegian Pollution Control Authority (SFT). Note that the scales used for the various metals differ (*Ærtebjerg et al., 2004*).

Heavy metals in sediment

The heavy metal content of sediment is measured in eight different types of open and coastal marine waters. The results are assessed in relation to the OSPAR Ecotoxicological Assessment Criteria (EAC) (*OSPAR, 1998*). The lead and cadmium content of the sediment in the Øresund exceeds the upper EAC, thereby entailing a possible risk that long-term exposure may negatively affect the most sensitive organisms (Figure 10.4).

In most waters the zinc, copper and mercury content of the sediment is between the upper and lower EACs, thus entailing that long-term effects on the ecosystem cannot be excluded.

Some regional authorities have given the copper content of mussels as a reason for a water body failing to meet its quality objective, while a few others have given the cadmium and mercury content. Some regional authorities have given the sediment content of lead and cadmium as a reason for lack of quality objective compliance.

AQUATIC ENVIRONMENT 2004 – Figure 10.4

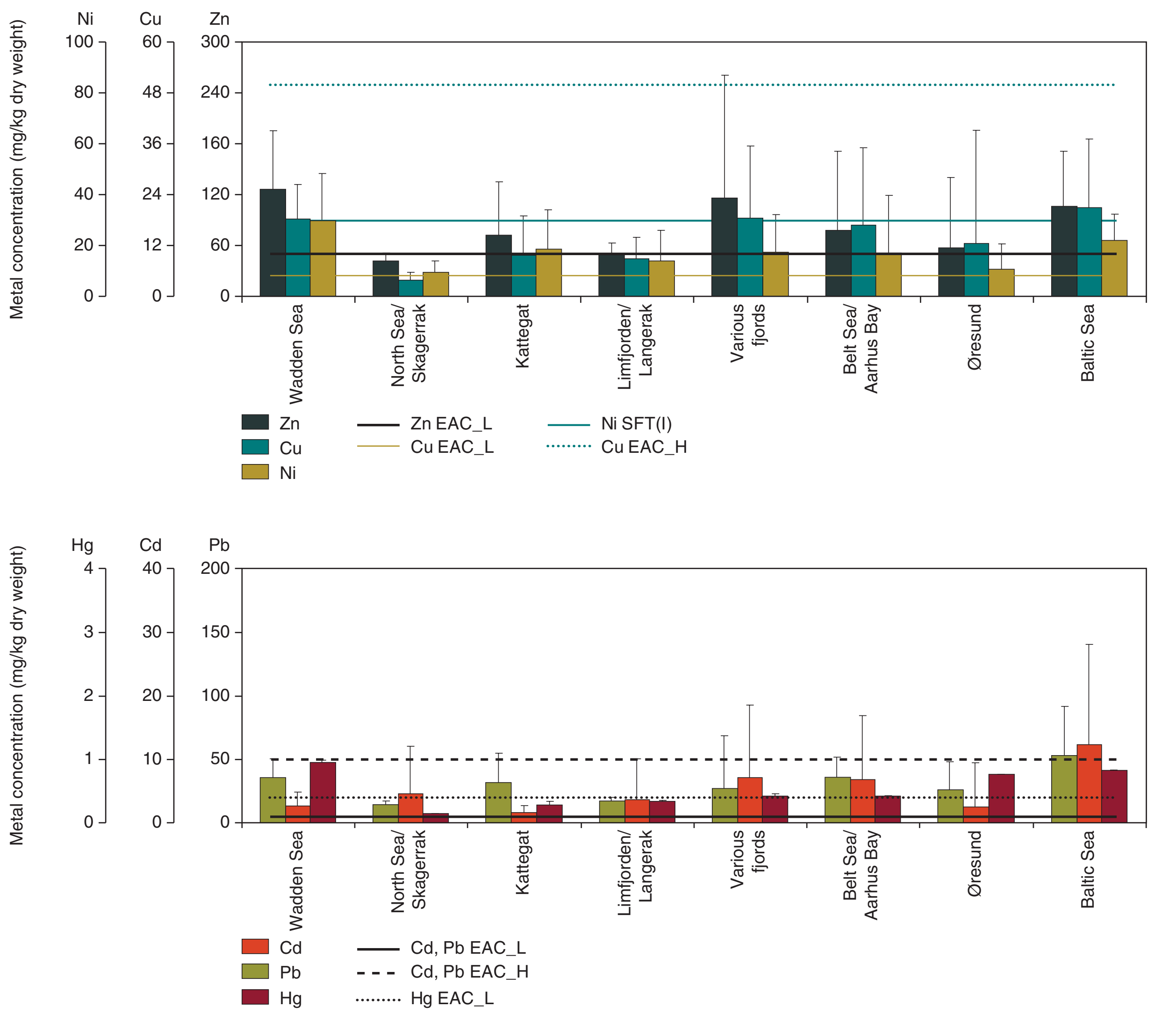


Figure 10.4 Metal concentrations (mg/kg dry matter) in sediment from various Danish marine waters. The horizontal lines indicate limit values. SFT (1): Norwegian Pollution Control Authority (SFT) class 1. EAC_L and EAC_H: OSPAR Ecotoxicological Assessment Criteria – H: High, L: Low. Note that the scales used for the various metals differ (*Ærtebjerg et al., 2004*).

11 Pesticides

Pesticides are widely used for combating weeds and pests in agriculture, forestry, market gardening, etc., as well as along roads, railroads, etc. Not all pesticides are completely degraded after they have had their intended effects, and pesticide residues and degradation products are therefore found dispersed throughout the environment.

The monitoring of pesticides and their degradation products in 2003 encompassed the groundwater, watercourses and lakes. In addition, pesticides are included to a limited extent in the monitoring of wastewater from wastewater treatment plants and industries with separate discharges.

The pesticides that are monitored in groundwater, watercourses and lakes are primarily herbicides used in agriculture and forestry. These include glyphosate, which has increasingly been used to combat weeds in recent years. The most frequent cause of pesticide contamination of groundwater, however, is BAM – a degradation product of dichlobenil (Prefix and Casoron G) and chlorthiamid (Casoron). These pesticides have been used for combating weeds on non-cultivated land such as along roads, railroads, paths, etc., but their use is no longer permitted.

Wastewater and sewage sludge is analysed for the so-called drins (aldrin, dieldrin, endrin, isodrin) and lindane. These are all chlorinated pesticides whose use is no longer permitted. None of these compounds have been detected in effluent from wastewater treatment plants.

In a few cases wastewater from separate industrial discharges has been analysed for some of the same pesticides as analysed for in groundwater and watercourses. In this connection, BAM has frequently been detected (in 41 out of 45 samples) with a mean concentration of 0.2 µg/l. At a few industries the wastewater has been analysed for certain other pesticides, and very high concentrations have been detected. For example, dichlorprop has been detected in eight out of 12 samples in a mean concentration of 2.7 µg/l, and mechlorprop has been detected in seven out of seven samples in a mean concentration of 9.3 µg/l.

11.1 State and trend in groundwater, watercourses and lakes

AMPA and glyphosate

Of the pesticides and degradation products monitored, the one most frequently detected in watercourses is AMPA. Thus of the 168 samples collected from five Danish watercourses in 2003, AMPA was found in 91%. AMPA is a degradation product of glyphosate, the active ingredient in products such as Roundup. Glyphosate is detected in 82% of the watercourse samples (Figure 11.1).

AMPA and glyphosate are also among the pesticides and degradation products most frequently detected in lakes. AMPA was present in seven out of the eight lakes investigated, while glyphosate was found in six. The median concentration of both substances was low in 2001 and 2003 (corresponding to the detection limit).

As in the lakes, AMPA and glyphosate are among the most frequently detected pesticides and degradation products in groundwater. They were most frequently detected in the younger near-surface groundwater in the agricultural monitoring catchments (Figure 11.2). The substances were also detected in the deeper groundwater, but far less frequently than in the near-surface groundwater.

In 2003, glyphosate accounted for 43% of all herbicide sales and 32% of total sales of pesticides for agricultural purposes (*Danish EPA, 2004b*). Sales have been increasing over the years, especially steeply in the past few years (Figure 11.3).

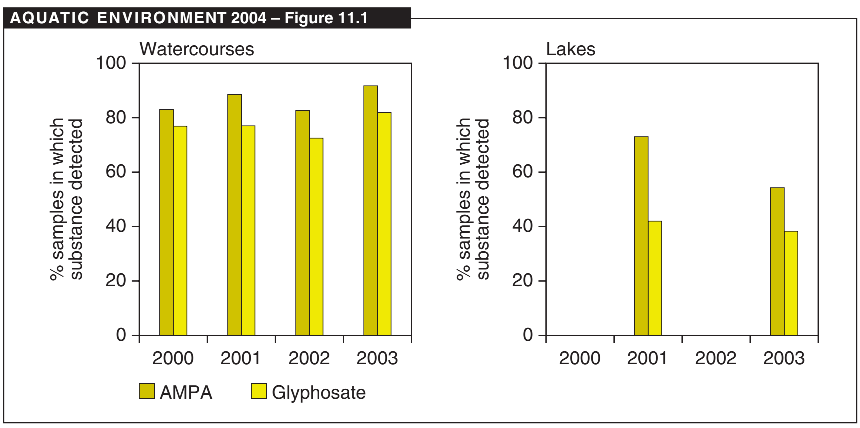


Figure 11.1 Occurrence of glyphosate and AMPA in watercourses and eight lakes over the period 2000–2003. Lakes were not investigated in 2000 and 2002 (data from *Bøgestrand (ed.), 2004* and *Jensen et al., 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 11.2

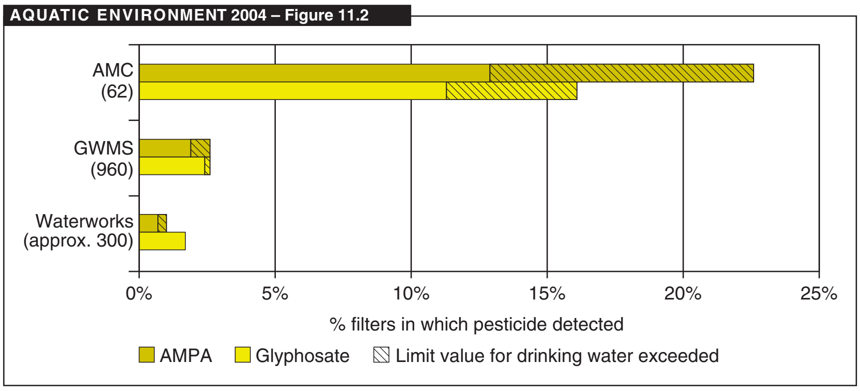


Figure 11.2 Groundwater filters/wells in which glyphosate and AMPA were detected and filters/wells in which the concentration exceeded the limit value for drinking water shown for the agricultural monitoring catchments (AMC), groundwater monitoring sites (GWMS) and waterworks control wells during the period 1998–2003. The figures in parentheses indicate the number of analysed filters/wells (data from *GEUS, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 11.3

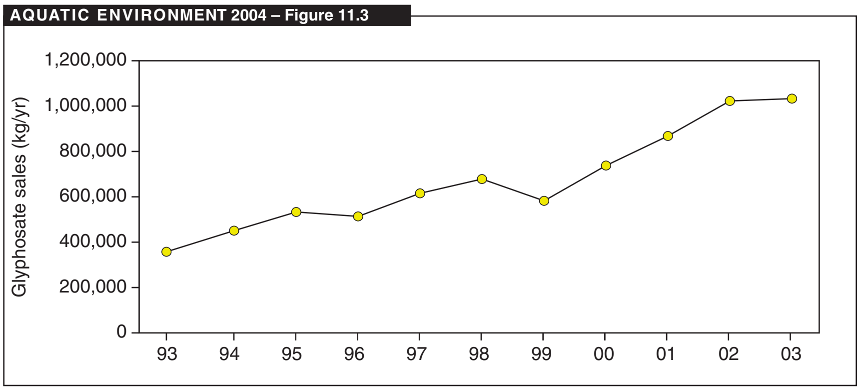


Figure 11.3 Trend in sales of glyphosate over the period 1993–2003 (data from *Danish EPA, 1995*; *Danish EPA, 1998*; *Danish EPA, 2001* and *Danish EPA, 2004b*).

AQUATIC ENVIRONMENT 2004 – Figure 11.4

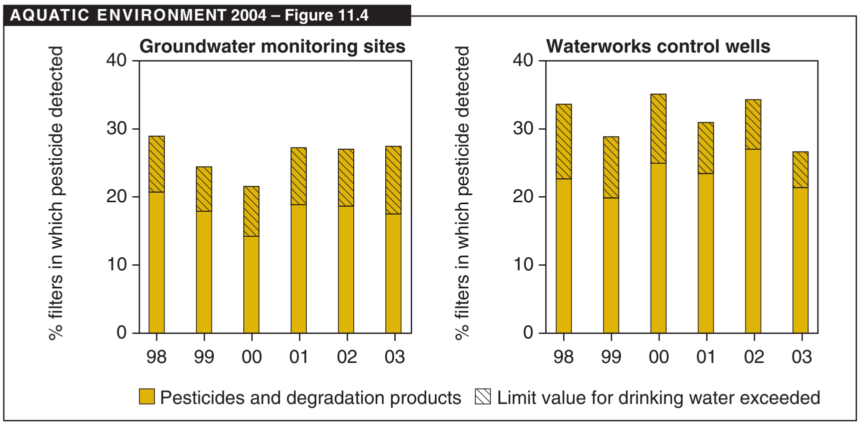


Figure 11.4 Filters in which pesticides and pesticide degradation products were detected over the period 1998–2003 at the groundwater monitoring sites and in the waterworks control wells (*GEUS, 2004*).

11.2 Other pesticides

Apart from AMPA and glyphosate, the pesticides most frequently detected in watercourses and lakes and to some extent also in groundwater are largely the same (Table 11.1).

At the groundwater monitoring sites the proportion of filters in which pesticides and degradation products have been detected has remained stable the past few years. However, the proportion of filters in which the pesticide concentration exceeds the limit value for drinking water (0.1 µg/l) has been increasing (Figure 11.4). The proportion of waterworks wells in which the limit value is exceeded has decreased during the same period, probably due to the closure of wells with high pesticide concentrations.

In surface water the Danish limit value for trichloroacetic acid (*Ministry of Environment and Energy, 1996*) was found to be exceeded on a single occasion in a watercourse. With another eight pesticides, Norwegian (*Ludvigsen et al., 2001*) or Dutch (*Crommentuijin et al., 1997*) limit values were found to be exceeded in 35 cases. No corresponding Danish limit values have yet been set. With other substances (dinoseb, isoproturon and propinicol), such high concentrations have sometimes been detected that they cannot be due to normal use of the substances, but are probably due to direct discharge to the watercourse.

AQUATIC ENVIRONMENT 2004 – Table 11.1

Watercourses (168 samples)	Lakes (48 samples)	GWMS (approx. 1,000 filters)	AMC (50–100 filters)	Waterworks (220–5,500 wells)
AMPA (91%)	TCA (61%)	BAM (20%)	4-nitrophenol (39%)	BAM (21%)
BAM (83%)	AMPA (54%)	DEI-atrazine (9,0%)	DEI-atrazine (30%)	4-nitrophenol (3,2%)
Glyphosate (82%)	BAM (54%)	DIP-atrazine (7,4%)	DIP-atrazine (23%)	4CPP (2,6%)
TCA (52%)	4-nitrophenol (50%)	DE-atrazine (6,8%)	AMPA (23%)	Atrazine (2,6%)
MCPA (39%)	Glyphosate (38%)	4-nitrophenol (6,6%)	Bentazon (21%)	DE-atrazine (2,6%)
Terbutylazine (32%)	DNOC (26%)	Atrazine (5,3%)	Glyphosate (16%)	Bentazon (1,9%)
Bentazon (32%)	MCPA (23%)	Dichlorprop (4,3%)	DE-atrazine (15%)	Mechlorprop (1,9%)

Table 11.1 Summary of the most frequently detected pesticides and pesticide degradation products in watercourses and lakes in 2003 and in groundwater at the groundwater monitoring sites (GWMS), in the agricultural monitoring catchments (AMC) and at waterworks calculated as the total for the period 1993–2003. The detection percentage for watercourses and lakes is given relative to the total number of samples analysed, while that for groundwater is given relative to the total number of filters/wells analysed (data from *Bøgestrand (ed.), 2004*; *Jensen et al., 2004* and *GEUS, 2004*).

12 Other organic micropollutants

The organic micropollutants include a number of chemicals on the EU list of endocrine disruptors, i.e. substances documented to cause hormonal disturbances. These include plasticizers, nonylphenol, PCB and organotin compounds (*Danish EPA, 2004a*). A number of the organic micropollutants that were in use for many years are now banned, but are still detectable in the environment and pose an environmental problem, e.g. PCB.

The monitoring of non-pesticide organic micropollutants in 2003 encompassed wastewater, sewage sludge, groundwater, watercourses and lakes, as well as mussels/clams, fish and sediment from marine waters. Some 150 substances were analysed for in 2003. Virtually all of these were analysed for in wastewater and sewage sludge, whereas fewer substances were analysed for in the other media depending on their use and physical-chemical properties.

A few substances were included in the analysis of nearly all the media, including nonylphenols, which are primarily used as detergents, and the plasticizer di(2-ethylhexyl)phthalate (DEHP). In contrast, PCB was only analysed for in wastewater and sewage sludge, and dioxins only in sewage sludge.

12.1 Wastewater

Wastewater is the most important source of the organic micropollutants found in the aquatic environment. The majority of the substances are frequently detected in the untreated wastewater received by the treatment plants, but in most cases the concentration is considerably lower in the treated wastewater. Many of the substances degrade during treatment, while others such as aromatic hydrocarbons, phenols, polyaromatic hydrocarbons and plasticizers are present in larger amounts in the sewage sludge.

Among the substances most frequently detected in effluent from wastewater treatment plants in 2003 are DEHP, nonylphenols, phenol, the phosphate triesters TCPP, tributyl phosphate and triphenyl phosphate, and the aliphatic amines diethylamine and dimethylamine. These substances were all found in more than half of the samples analysed.

12.2 State and trend

Watercourses and lakes

In 2003, 31 different organic micropollutants were detected in one or more water samples from the five major watercourses investigated. Thus more substances were detected than in 2002.

Their occurrence is so dispersed, however, that no general pattern emerges. As a consequence it is only possible to reliably calculate input to the sea for trichloroethylene, and only for one of the five watercourses (the river Damhusåen). Input of trichloroethylene to the sea via this watercourse amounted to 4.8 kg in 2003. Trichloroethylene was detected in 9% of the wastewater treatment plant effluent samples analysed, and in concentrations that were considerably lower than both the median and maximum concentration in the river Damhusåen.

DEHP and nonylphenols, which are among the substances most frequently detected in wastewater treatment plant effluent, were detected in four and three, respectively, of the 60 watercourse samples analysed in 2003. Five of the seven samples in which these two substances were detected came from the river Damhusåen. In the lakes, DEHP was detected in 14% of the samples analysed, which is less than in 2001, when DEHP was detected in 26% of the samples analysed.

The concentrations of organic micropollutants detected in the eight lakes investigated in 2003 were generally low. To the extent that the concentration at which the individual substances have ecotoxicological effects is known, it is concluded that the substances detected are unlikely to have individual ecotoxicological effects. No conclusions can be drawn as to ecotoxicological effects of the substances in combination, however.

AQUATIC ENVIRONMENT 2004 – Table 12.1

	No. of wells/filters analysed	Wells/filters in which one or more substances have been detected
Groundwater monitoring sites	1,132	63% of analysed
Agricultural monitoring catchments	61	56% of analysed
Waterworks control wells	5,628	22% of analysed

Table 12.1 Detection frequency of non-pesticide organic micropollutants in groundwater in the period 1993–2003. Samples containing anionic detergents are not included (*GEUS, 2004*).

Groundwater

The groundwater concentration of a number of non-pesticide organic micropollutants has been monitored since 1993.

The proportion of filters in which one or more of the monitored substances have been detected at least once during the period 1993–2003 is generally greater at the groundwater monitoring sites than in the agricultural monitoring catchments and waterworks wells (Table 12.1).

The proportion of contaminated samples has been roughly the same each year during the period at the groundwater monitoring sites and waterworks wells, without any clear tendency towards an increase or decrease (Figure 12.1). Thus the proportion of filters in which organic micropollutants were detected was higher in 2003 than in 2002 at the groundwater monitoring sites, but lower in the waterworks wells.

The organic micropollutants most frequently detected at the groundwater monitoring sites are the aromatic hydrocarbons (benzene, toluene and xylenes) (Figure 12.2). That most frequently detected in the agricultural monitoring catchments is phenol, while that most frequently detected in the waterworks wells is the plasticizer DBP.

The data from the groundwater monitoring sites show that many of the substances have penetrated deep down into the ground. For example, chloroform has been detected at a depth of 40 m b.g.s. Of the 11,090 filters investigated for chloroform, the substance was detected in 111. Some of the filters in which chloroform was detected lie in areas covered by forest or semi-natural countryside. Its presence there may be attributable to natural formation, it being known that chloroform can be formed naturally under forest soils. Such formation of chloroform is especially likely to occur in coastal conifer forests, where chlorine from the sea air is trapped by the trees and thereafter drips to the forest floor.

AQUATIC ENVIRONMENT 2004 – Figure 12.1

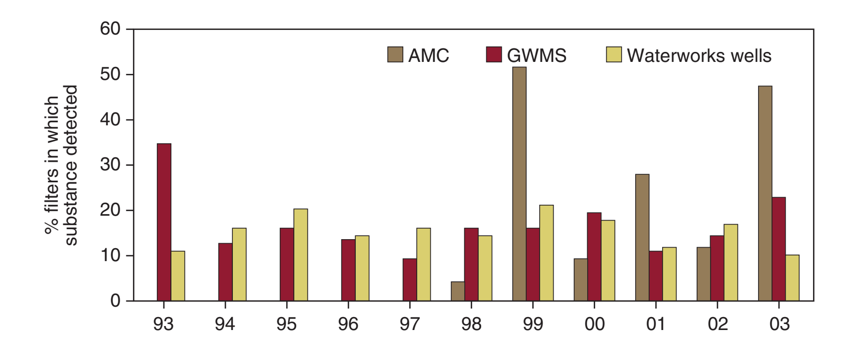


Figure 12.1 Trend in detection frequency of organic micropollutants in the agricultural monitoring catchments (AMC) over the period 1998–2003 and at the groundwater monitoring sites (GWMS) and waterworks wells (well control) over the period 1993–2003. The detection frequencies indicate the percentage of filters in which one or more substances have been detected in concentrations exceeding the detection limit relative to the total number of filters analysed (data from *GEUS, 2004*).

AQUATIC ENVIRONMENT 2004 – Figure 12.2

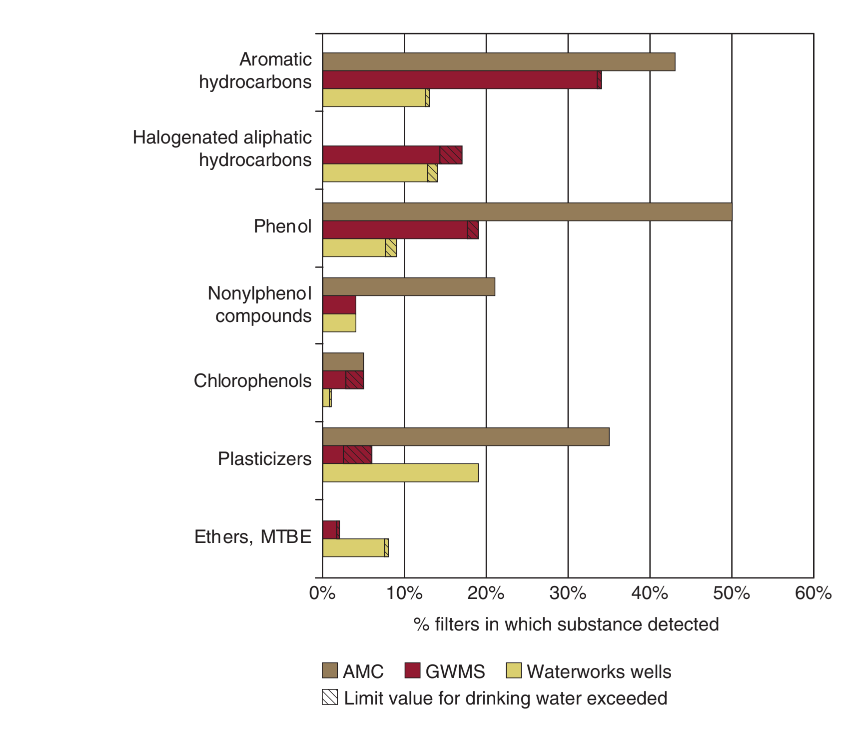


Figure 12.2 Detection frequency of various groups of organic micropollutants in the agricultural monitoring catchments (AMC) and at the groundwater monitoring sites (GWMS) and waterworks wells (well control). The detection frequencies indicate the percentage of filters in which the substances have been detected in concentrations exceeding the detection limit relative to the total number of filters analysed in the period 1993–2003 (1998–2003 for the agricultural monitoring catchments) (data from *GEUS, 2004*).

Marine waters

In 2003, sediment from the monitored fjords and inner marine waters was found to contain all the organic micropollutants analysed for (Figure 12.3). Various organochlorines such as PCB, DDT, lindane (HCH) and hexachlorobenzene (HCB) were detected in sediment, mussels/clams and fish. PAH and organotin compounds were detected in sediment and mussels/clams, and DEHP and nonylphenols (NP) were detected in sediment.

The occurrence of organic micropollutants in the marine waters is primarily assessed relative to the OSPAR Ecotoxicological Assessment Criteria (EAC) (*OSPAR, 1998*), but also relative to the Norwegian classification system (*Norwegian Pollution Control Authority, 1997*).

In several areas, PCB and PAH were detected in sediment and mussels in concentrations at which ecotoxicological effects cannot be ruled out.

Tributyl tin (TBT) is widespread in marine sediments, the concentrations

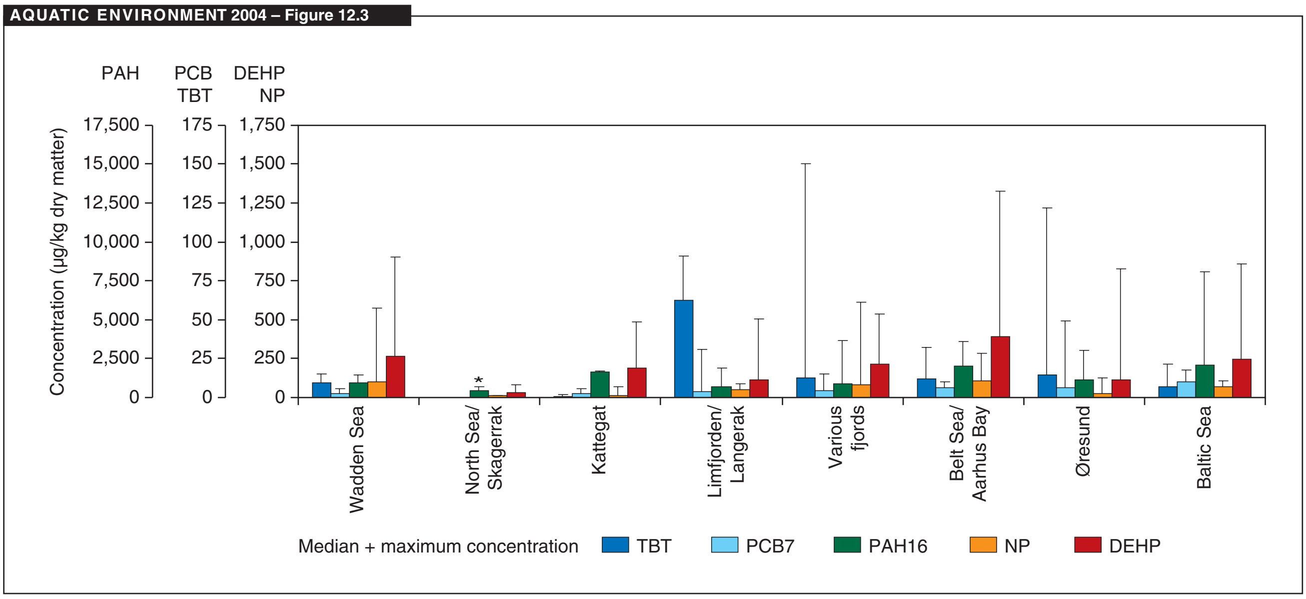


Figure 12.3 Concentration of selected organic micropollutants in sediment in coastal and open parts of the Danish marine waters. Note that the scales used for the various substances differ (*Ærtebjerg et al., 2004*).

in coastal waters being higher than in the open marine waters. The EAC for TBT is very low, and the concentrations detected can be expected to have widespread effects in all marine waters. In all the areas investigated TBT was detected in mussels/clams in such high concentrations that there is a major risk of ecotoxicological effects. The concentrations were highest in areas with heavy shipping and other shipping-related activities. TBT has been widely used as an antifouling agent in hull paints, but measures to phase out its use were implemented in 2003.

The effects of TBT in marine waters are very visible in the form of endocrine disruption among gastropod molluscs: females develop permanent male sexual characteristics that in the worst instance can lead to sterility (imposex[1] and intersex[2]). The degree of imposex is quantified using an index value, the Vas Deferens Sequence Index (VDSI). The relationship between sediment TBT concentration and VDSI indicates that gastropod molluscs differ in their sensitivity to TBT (Figure 12.4). In 2003, imposex and intersex were found to be widespread in the five species of gastropod molluscs investigated. In the most sensitive species this was even the case in the open marine waters (Figure 12.5).

Several regional authorities have given the presence of organic micropollutants as one of the reasons for a water body failing to meet its quality objective.

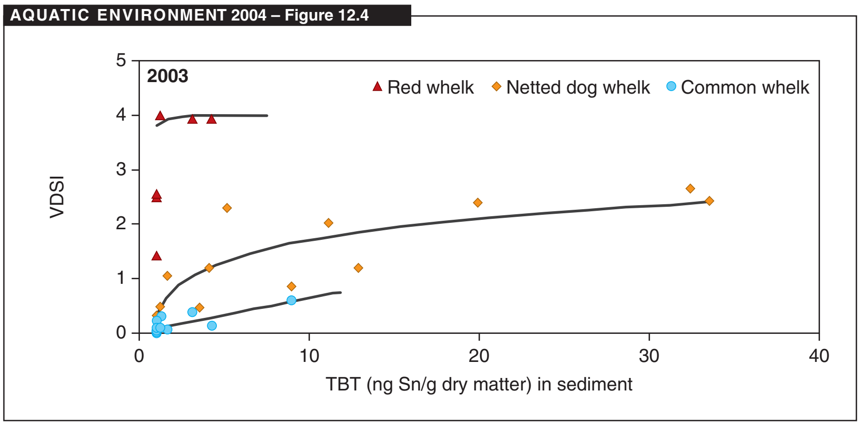


Figure 12.4 Imposex in relation to the TBT content of the sediment; VDSI: Vas Deferens Sequence Index (after Figure 16.3 in *Ærtebjerg et al., 2004*).

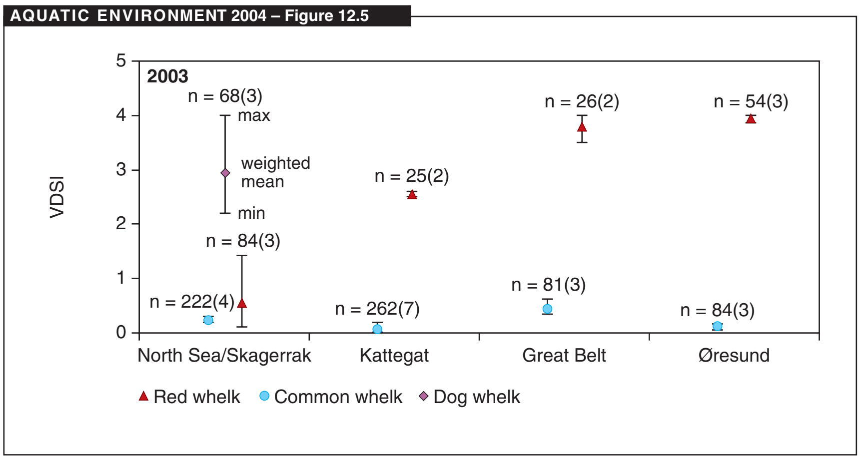


Figure 12.5 Imposex in red whelk, common whelk and dog whelk in four Danish marine waters. n = number of females. The number of stations is given in parentheses (after Figure 16.1 in *Ærtebjerg et al., 2004*).

1) Imposex: The development of hermaphroditism in gastropods due to TBT-induced endocrine disruption. The females develop a penis and/or vas deferens in addition to the normal female sexual organs.
2) Intersex: The development of hermaphroditism in gastropods and fish, etc. due to endocrine disruption. In the common periwinkle the female's normal sexual organs are actually transformed to male sexual organs.

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PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 46 30 12 00
Fax: +45 46 30 11 14

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National Environmental Research Institute
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DK-8600 Silkeborg
Denmark
Tel: +45 89 20 14 00
Fax: +45 89 20 14 14

Monitoring, Research and Advice Secretariat
Department of Marine Ecology
Department of Terrestrial Ecology
Department of Freshwater Ecology

National Environmental Research Institute
Grenåvej 12-14, Kalø
DK-8410 Rønde
Denmark
Tel: +45 89 20 17 00
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