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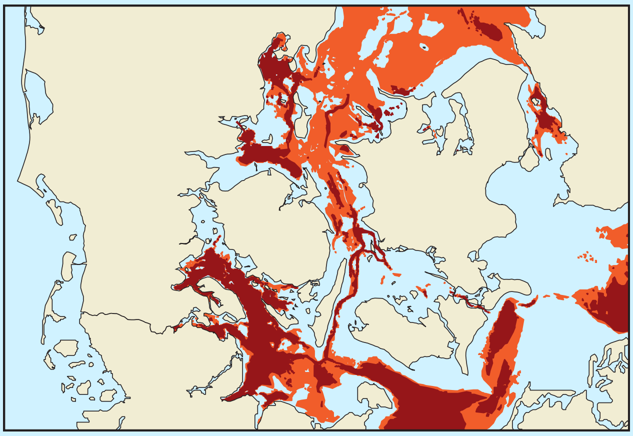
Aquatic Environment 2003

State and trends – technical summary

NERI Tecchnical Report, No. 500



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2004

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Data sheet

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Abstract: This report provides the results from 2002 of the Danish Aquatic Monitoring and Assessment Programme 1998-2003. The report describes the technical conclusions on the state and trend of Danish groundwater, streams, lakes, atmosphere and marine waters. The report is based on the annual reports elaborated by the topic centres on each subprogramme. These reports are based on data collected and, in most cases, also reported by the Danish county authorities.

Keywords: Action plan on the aquatic environment, environmental state, groundwater, lakes, marine waters, atmospheric deposition, wastewater, discharges, agriculture, nitrogen, phosphorus, pesticides, heavy metals, environmental pollutants, oxygen depletion

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Content

AQUATIC ENVIRONMENT 2003

State and trends – summary of investigation results 2002

Restoration of river Skjern, 2002.

This report provides the technical conclusions of the results from 2002 of the Danish Aquatic Monitoring and Assessment Programme 1998-2003 (NOVA 2003) (*Danish EPA, 2000*). The report summarizes the development in the environmental state of the aquatic environment during 2002 and describes the trends in the development of environmental quality during 1989-2002.

This summary is primarily meant as a briefing to the Environment and Planning Committee of the Danish Parliament about the results of the annual monitoring and the effects of the measures and investments described in the 1987 report on the Action Plan on the Aquatic Environment. The summary furthermore provides a national overview for the benefit of the institutions at state and county level that have contributed to the implementation of the monitoring programme, or are involved in the management of the aquatic environment. Finally, the summary will provide the general public and non-governmental organisations with essential information on the state and trends of the aquatic environment. The report was prepared by the National Environmental Research Institute (NERI) in cooperation with the Geological Survey of Denmark and Greenland (GEUS) and the Danish EPA based on reports elaborated by the seven topic centres at these institutions.

The reports are based on data collected by the Danish county authorities and the municipalities of Copenhagen and Frederiksberg. Most data can also be found in regional reports with the original background information that is the basis of the topic centre reports.

AQUATIC ENVIRONMENT 2003 – Background reports (in Danish)

Vandløb 2002.	(Streams 2002)	*Bøgestrand (ed.), 2003.*
Atmosfærisk deposition 2002.	(Atmospheric deposition 2002)	*Ellermann et al., 2003.*
Landovervågningsoplande 2002.	(Agricultural monitoring catchments 2002)	*Grant et al., 2003.*
Grundvandsovervågning 2002.	(Groundwater monitoring 2002)	*GEUS, 2003.*
Marine områder 2002.	(Marine waters 2002)	*Rasmussen et al., 2003.*
Søer 2002.	(Lakes 2002)	*Jensen et al., 2003.*
Punktkilder 2002.	(Point sources 2002)	*Danish EPA, 2003.*

Summary

The main conclusion of the Danish Aquatic Monitoring and Assessment Programme (NOVA-2003) in 2002 is that there have been marked reductions in nutrients discharged with wastewater and discharges from cultivated areas since 1989. These reductions have improved the natural and environmental conditions in lakes and marine waters. A beginning reduction in the nitrate content in the upper, newly formed groundwater in sandy areas has been observed. The environmental quality in streams is determined mainly by the hydromorphological conditions and the input of organic matter, and the environmental conditions in streams have improved slightly during the recent 4 years.

In spite of the improvements, only a minority of the water bodies complied with the quality objectives and the most comprehensive oxygen deficiency hitherto observed in inner Danish marine waters was measured in 2002.

Pollution sources: Organic matter, nitrogen and phosphorus

Compared to a climatically normal year, pollution from most sources was higher in 2002 due to high precipitation. The result of high precipitation is not only increased leaching of nitrogen and phosphorus from farmland, but also increased atmospheric deposition and higher discharges from urban areas.

Table 1 shows a total list of the Danish sources of pollution of water bodies, and the atmospheric input to the Danish marine territory. The main nitrogen sources are cultivation of land and atmospheric deposition. The greatest phosphorus load derives from cultivation of the land although the wastewater load as a whole was at the same level.

Contributions of organic matter from the various sources of pollution are not directly comparable with the background loss because the quality of the organic matter in wastewater is different from that of naturally occurring substances. The polluting effect is therefore relatively higher.

Wastewater treatment plants

Organic matter (BOD_5) and the nutrients nitrogen (N) and phosphorus (P) are generally removed efficiently in the wastewater treatment plants. Since the mid-1980s, i.e. before the implementation of the Danish Action Plan on the Aquatic Environment and until 2002, there has been a reduction in the discharges of BOD_5, N and P of 96%, 77% and 91%, respectively. Particularly discharges of BOD_5 and phosphorus as a whole are now considerably below the requirements of the Action Plan on the Aquatic Environment. Most plants encompassed by the general requirements of the Action Plan on the Aquatic Environment consequently achieve BOD_5 concentrations of 2-4 mg/l and phosphorus concentrations of 0.2-0.5 mg/l. According to the Action Plan on the Aquatic Environment, the general requirements to BOD_5 and phosphorus are 15 and 1.5 mg/l, respectively, for plants with more than 5,000 persons connected to the plant.

Enterprises

Separate industrial dischargers have reduced their pollution to the same extent as the wastewater plants. Pollution from freshwater fish farms and marine fish farms was also reduced somewhat although the relative reduction is far much lower than that from treatment plants and industry.

Leaching from cultivated areas

Nutrient leaching from cultivated areas is influenced by cultivation practices, fertilizer consumption and the character of the areas. The amount of nitrogen in the applied commercial fertilizer was reduced from 395,000 tonnes in 1985 to 206,000 tonnes in 2002. This has contributed to a reduction in nitrogen leaching from cultivated areas during the period 1989-2002. The measured mean reductions in nitrate leaching from the root zone constituted 32% in clayey areas and 47% in sandy areas (to 14 and 18 mg N/l, respectively), but with large deviations of the results. Nationwide model calculations show a reduction in nitrogen leaching from 41% to 70 kg N/hectares per year.

AQUATIC ENVIRONMENT 2003 – Table 1

Nutrient sources 2002	Organic matter (BOD_5) (tonnes/year)	Nitrogen (tonnes/year)	Phosphorus (tonnes/year)
Natural losses (reference)	11,100	12,700	440
Agriculture	7,300	74,900	1,160
Wastewater treatment plants	2,670	4,528	510
Urban stormwater	9,000	1,006	250
Wastewater from scattered dwellings	3,800	970	220
Industry with direct wastewater discharge	5,913	753	50
Freshwater aquaculture	3,276	1,180	94
Marine aquaculture	1,745	307	31
Atmospheric load to the sea	-	107,000	400
Total sources	**45,000**	**203,000**	**3,200**

Table 1 Total sum of input sources of organic substances and nutrients to water bodies in Denmark in 2002. (Figures from *Danish EPA, 2003* and *Bøgestrand (ed.), 2003).*

Phosphorus in commercial fertilizer was reduced from 47,800 tonnes in 1985 to 13,800 tonnes in 2002, and livestock manure is generally the predominant type of phosphorus fertilizer in Denmark. The phosphorus input from livestock farms still exceeds the amount removed from the fields with the crops (figure 1).

There are marked interannual variations in phosphorus losses from Danish agricultural land depending on the precipitation. No general efforts have been made to reduce phosphorus losses and the monitoring results do not indicate a trend in the losses of phosphorus from cultivated land.

Atmospheric nitrogen deposition

Nitrogen deposition on land areas varies typically between 10 and 25 kg N/ha per year with the highest deposition in areas with large livestock herds and high precipitation. Deposition on the sea is somewhat lower (7-15 kg N/ha per year) because of the generally wider distance to the pollution sources, and lower precipitation. The most important pollution sources are nitrogen oxides deriving from combustion processes and ammonia volatilization from livestock manure. During the period 1989-2002 there was an estimated reduction of approx. 17% in the total atmospheric deposition of nitrogen compounds on Danish marine waters.

Water bodies

Groundwater

The total groundwater abstraction in 2002 constituted 653 million m^3. Since 1989 there has been a marked decline in the amount of abstracted water, mainly due to a reduction in the consumption of the public common waterworks from 640 million m^3 in 1989 to 410 million m^3 in 2002.

Nitrate concentrations are highest in the upper groundwater formed within the recent decades. Under cultivated fields in the agricultural monitoring catchments, 29% of the water intakes contained more than 50 mg NO_3^-/l in 2002. There is an apparent reduction in nitrate concentrations in the upper groundwater. Figure 2 illustrates the trend in nitrate concentrations in the oxic upper groundwater in the groundwater monitoring areas. The figure reveal large deviations with an apparently slight increase throughout most of the 1990s and a slight decrease since the late 1990s.

Pesticide pollution in groundwater is primarily found in the subsurface groundwater, but the depth distribution of pesticide findings shows that pesticides are also found at depths exceeding 30 metres. Triazines and their metabolites are detected frequently in both groundwater and streams. Atrazine, which has been banned since 1984, contributes to some of these findings. A pool of the substance has probably been accumulated in the root zone and is slowly leaching from here.

Lakes

The environmental state of the monitoring programme lakes as a whole has improved since 1989. This is reflected in, for instance, the average Secchi depth in the lakes. Improvements are seen in lakes, where measures against phosphorus inputs from wastewater have been introduced before or after 1989. Improvements are generally not observed in lakes that do not receive wastewater. In these lakes the predominant source of pollution is phosphorus lost from cultivated areas in the catchment and this loss has not declined. In order to comply with the quality objectives of those lakes where the majority of the catchment is cultivated, a reduction in phosphorus leaching from the lake catchments is required. This applies to most Danish lakes.

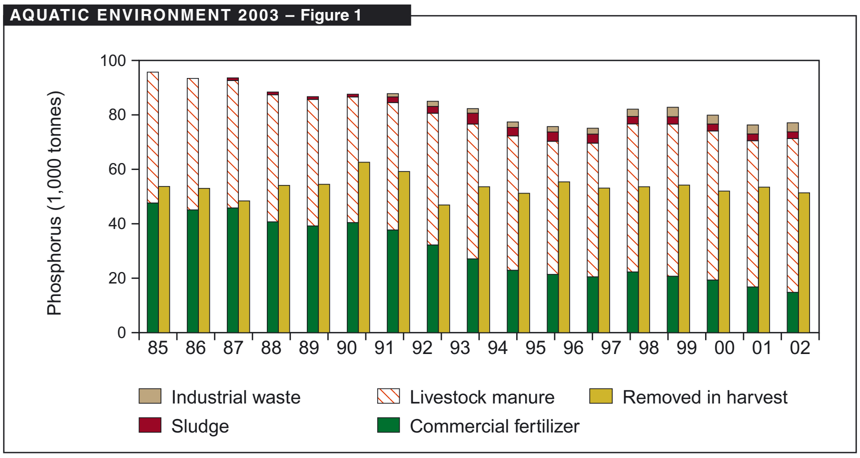


Figure 1 Trend in assigned phosphorus and harvested phosphorus for the total Danish agricultural land during the period 1985-8002. *Grant et al., 2003.*

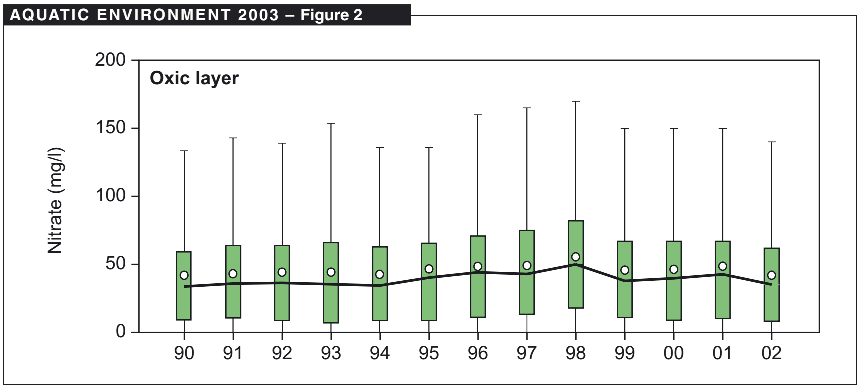
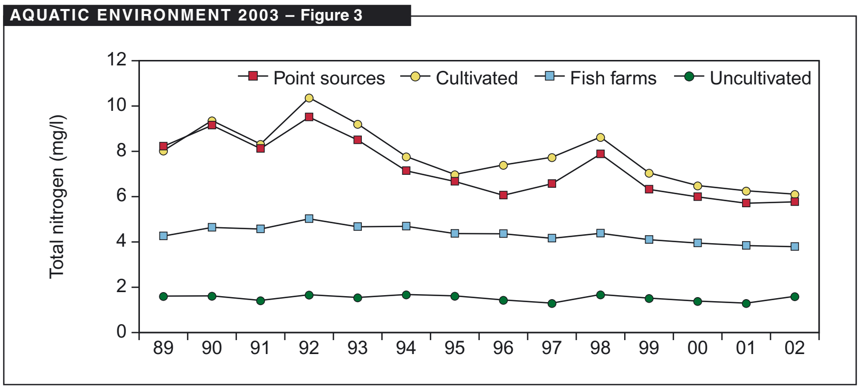
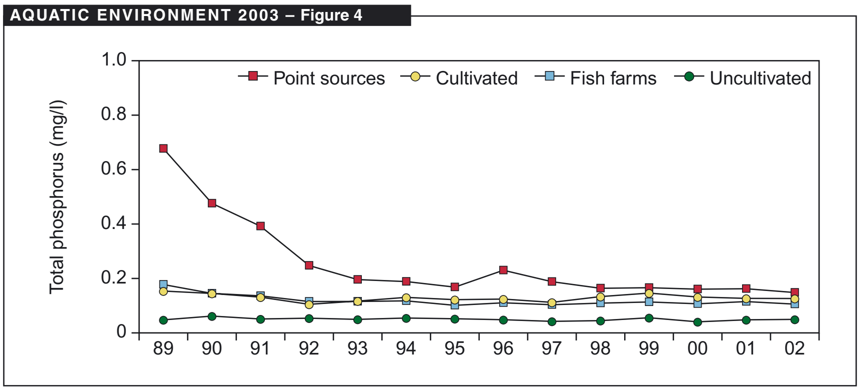
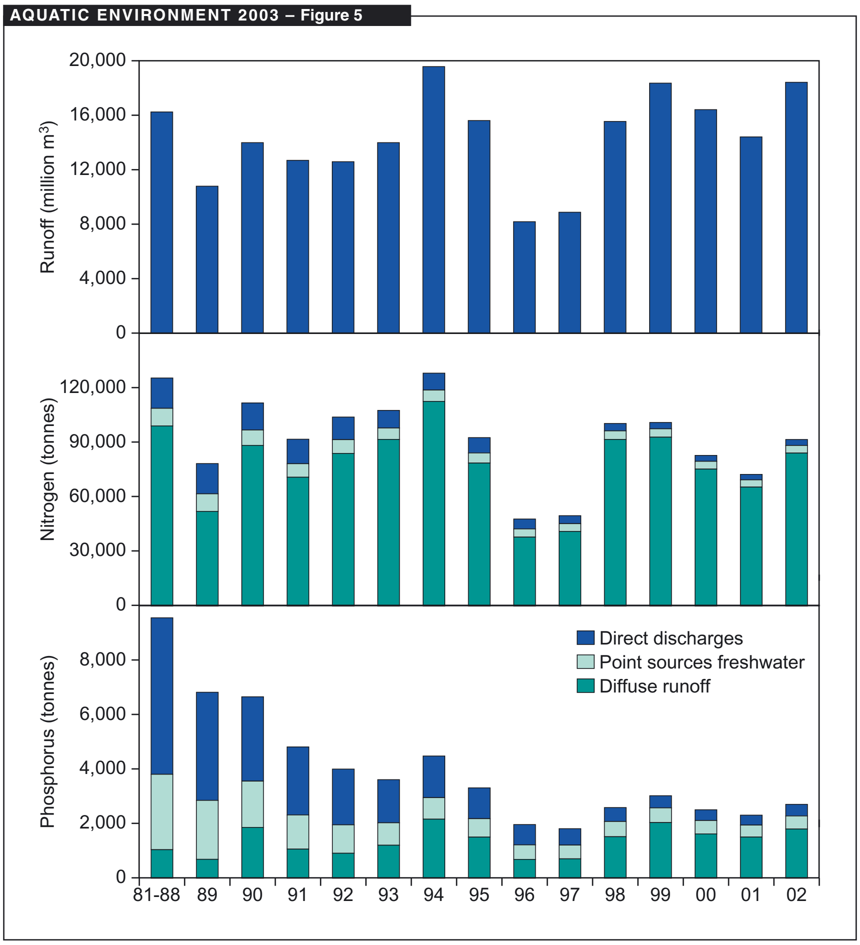


Figure 2 Nitrate trend in mg NO_3/l for the period 1990-2002 in water samples from the upper, oxic part of the GRUMO areas. It is in this part of the groundwater aquifers that a reduction in nitrate concentrations due to reduced leaching will be registered. *GEUS, 2003.*







Streams

Danish streams are especially impacted by the physical changes in the natural course of the streams in form of weirs, straightening and stream maintenance. Many streams were previously also contaminated by organic matter from wastewater, but this pollution was largely relieved by wastewater treatment initiated in the 1970s.

The biological quality of streams has gradually and slowly improved over the recent decades. The same station network and assessment method have been used since 1999. Investigations reveal that the proportion of streams with unaffected or slightly affected macroinvertebrate fauna has increased from 35% to just over 44% during this period. Conditions are generally worst in small streams and streams on the islands east of the Great Belt.

The biological conditions in Danish streams are only slightly affected by the nutrient concentrations, but the streams transport the nutrients to lakes and marine waters, where the input of nutrients is a major pollution source.

Figure 3 Trend in nitrogen concentrations since 1989. Average of flow-weighted annual mean values for streams subjected to different pressures. *Bøgestrand (ed.), 2003.*

Figure 4 Trend in phosphorus concentrations since 1989. Average of flow-weighted annual mean values for streams subjected to different pressures. *Bøgestrand (ed.), 2003.*

Figure 5 Annual freshwater runoff and input of nitrogen and phosphorus via streams and direct wastewater discharges to marine waters from 1989 to 2002 and the average for the period 1981-88. *Bøgestrand (ed.), 2003.*

Nitrogen and phosphorus concentrations in Danish streams have generally declined since 1989. Nitrogen concentrations have fallen with an average 2 mg N/l or approx. 30%, mainly as a consequence of reduced leaching from cultivated fields (figure 3). The concentrations started declining in the early 1990s. Phosphorus concentrations were reduced with just over 40% since 1989, but the reduction probably started earlier as a result of phosphorus removal from wastewater, which was initiated before 1989 (figure 4).

Transport from land to the sea

The level of pollution in Danish coastal waters is largely determined by nutrient inputs from the land. Figure 5 shows the trend in the annual input of water, nitrogen and phosphorus from Danish land areas to the Danish coastal waters. For each year the inputs of nitrogen and phosphorus are divided into diffuse sources (leaching from the soil), point sources to freshwater (wastewater) and direct wastewater discharges to coastal waters. In spite of the general discharge reductions, figure 5 shows that there has been considerable nutrient transport to marine waters during the recent 5 years. This is related to the levels of precipitation and runoff from Denmark being higher than normal in all 5 years.

Marine waters

The major, general source of pollution of Danish marine waters is the input of nitrogen and phosphorus from land and air. The shallow Danish marine waters are more vulnerable towards eutrophication than most other marine waters because the water exchange with the open sea is often limited, and because the stratification of the water column often restricts the supply of oxygen to the water close to the bottom.

In 2002, the inner Danish marine waters were hit by the worst case ever of oxygen depletion culminating in late September. Figure 6 shows that the most severely affected areas were the areas along the east coast of Jutland and south of Funen. Large areas in the southern Kattegat were also affected. The oxygen depletion resulted in dead benthic invertebrates and fish in the affected areas. The oxygen depletion was attributable to a combination of several factors: high precipitation and high nutrient inputs, water temperatures above the normal and a late summer with no strong winds.

In spite of the comprehensive oxygen depletion in 2002 there are some indications of improvements in the state of the marine waters. Nutrient concentrations in fjords and coastal waters are now on the decrease and the algal production is increasingly being limited by the lack of nitrogen and phosphorus. Since the 1980s there are also clear indications of improvement in the Secchi depth in fjords and coastal waters and of a decrease in the algal abundance and production. These improvements have, however, not yet resulted in improved conditions for macrophytes (including eelgrass) or benthic invertebrates. Similarly, there are no signs of improvements in the oxygen content in the water close to the bottom, neither in fjords and coastal waters nor in the open marine waters.

The concentration of heavy metals found in fish varies. In fish from the Sound the mercury concentrations are generally high. Exeedence of the consummation limit values was observed in one flounder filet.

AQUATIC ENVIRONMENT 2003 – Figure 6

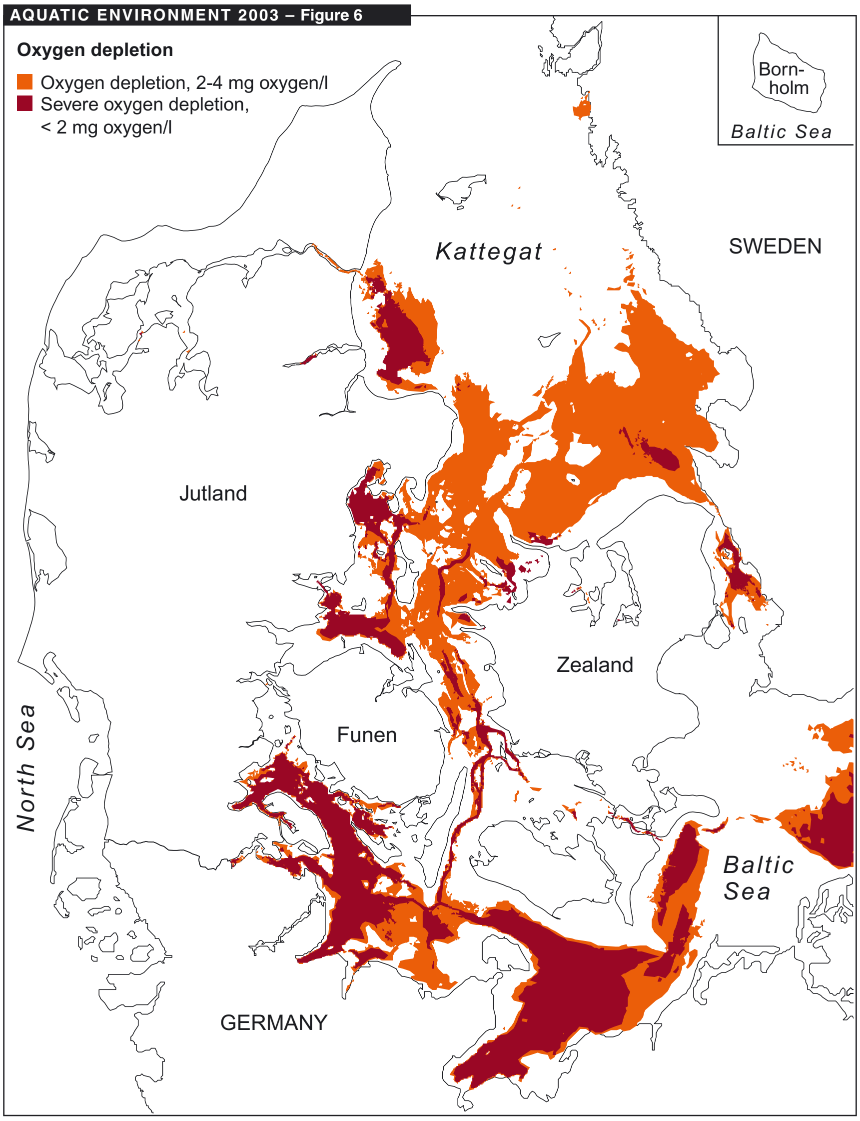


Figure 6 The extent of oxygen deficiency and severe oxygen deficiency during the period 30 September to 4 October 2002. *Rasmussen et al., 2003.*

Quality objective compliance

The various examples of compliance with the current quality objectives in water bodies described below do not fully reflect the level of anthropogenic impact because the specific requirements of the county councils to each water body may vary.

Wastewater treatment plants

Out of the 266 plants encompassed by the requirement of Danish Action Plan on the Aquatic Environment, only one plant did not comply with the general phosphorus requirement, and only two plants did not comply with the nitrogen requirement, while all plants complied with the BOD_5 requirement. Out of all 1,060 treatment plants in Denmark, exceedences of one or more of the stipulated specific discharge requirements were only recorded in 71 plants in 2002.

Losses from cultivated fields

The quality objective of the action plans for the aquatic environment is an approx. 50% reduction in nitrogen leaching from the root zone in cultivated areas. On the basis of the monitoring results the reduction in leaching is calculated at 41% in relation to leaching in the 1980s. In addition, there is a minor reduction in nitrogen transport via streams because of the nitrogen removal that takes place in the re-established wetlands introduced as a part of the Action Plan on the Aquatic Environment II. The evaluation report on the Action Plan on the Aquatic Environment II concludes that the prognosis of the total effect of the action plans on the aquatic environment shows a total reduction of almost 150,000 tonnes N/year, corresponding to approx. 48% of the leaching of 310,000 tonnes N/year in the 1980s (*Grant & Waagepetersen, 2003*).

Groundwater

Groundwater is most importantly used for water consumption. Only approx. 1% of the water supply abstraction wells did not comply with the limit values for nitrate in drinking water (50 mg NO_3^-/l). This result was, however, achieved by closing down wells with high nitrate concentrations and does therefore not reflect the general groundwater quality. In the groundwater monitoring areas more than 50 mg NO_3^-/l were detected in 16% of the wells.

37% of the groundwater used for drinking water in 2002 contained pesticides, of which 4% had pesticide concentrations exceeding the limit values for drinking water.

Lakes

The counties have estimated that only 4 of the 31 examined lakes complied with the quality objectives in 2002, which is a decrease of 3 lakes since 2000. Some of the lakes will experience improved conditions when the internal phosphorus release deriving from the wastewater discharges of the past has ceased. The majority of lakes will, however, only be able to comply with the quality objectives if phosphorus inputs from agricultural catchments and scattered dwellings are also reduced.

Streams

The environmental condition of streams is best in Jutland, on Funen and Bornholm, where approx. 55% of the quality objectives of streams are met, in contrast to only a third of the streams on the islands east of the Great Belt. Quality objective compliance on a national level was 50% in total. In order for the rest of the streams to comply with the current objectives, it is necessary to change the stream morphology to resemble the natural conditions with varied types of stream bed. Furthermore, many small streams are still polluted by insufficiently treated wastewater, particularly from scattered dwellings. However, clear-water fauna is prevented in many streams by a natural small slope of the stream and by summer drought.

Marine waters

The assessment of the councils and NERI is that only a few of the Danish marine waters comply with the quality objectives. Only one of the investigated shallow coastal areas (Dybsø Fjord) is assessed as complying with the quality objectives. Beyond this the open marine waters of the North Sea and Skagerrak are also assessed as having complied with the quality objectives. Reasons for non-compliance with the quality objectives is serious impact on plant and animal community due to increased nutrient concentrations, and in some places also high concentrations of tributyltin (TBT).

1 Introduction

1.1 Organisation and content of the Danish Aquatic Monitoring and Assessment Programme

The majority of the monitoring is carried out by the county authorities. In 2003 NERI was responsible for monitoring of the extensive marine monitoring stations, measurements and calculation of atmospheric deposition and the operation of a network of 22 national stations for the determination of stream water flow.

Monitoring stations in the NOVA-2003 programme
The principal monitoring stations and monitoring areas of the NOVA programme are shown in figure 1.1. Not included, however, are monitoring stations for wastewater discharge and the waterworks' control of the water quality of abstraction wells as well as the majority of stream monitoring stations.

Further information on NOVA-2003
A detailed description of the NOVA-2003 monitoring programme can be found in *Danish EPA, 2000*.

AQUATIC ENVIRONMENT 2003 – Figure 1.1

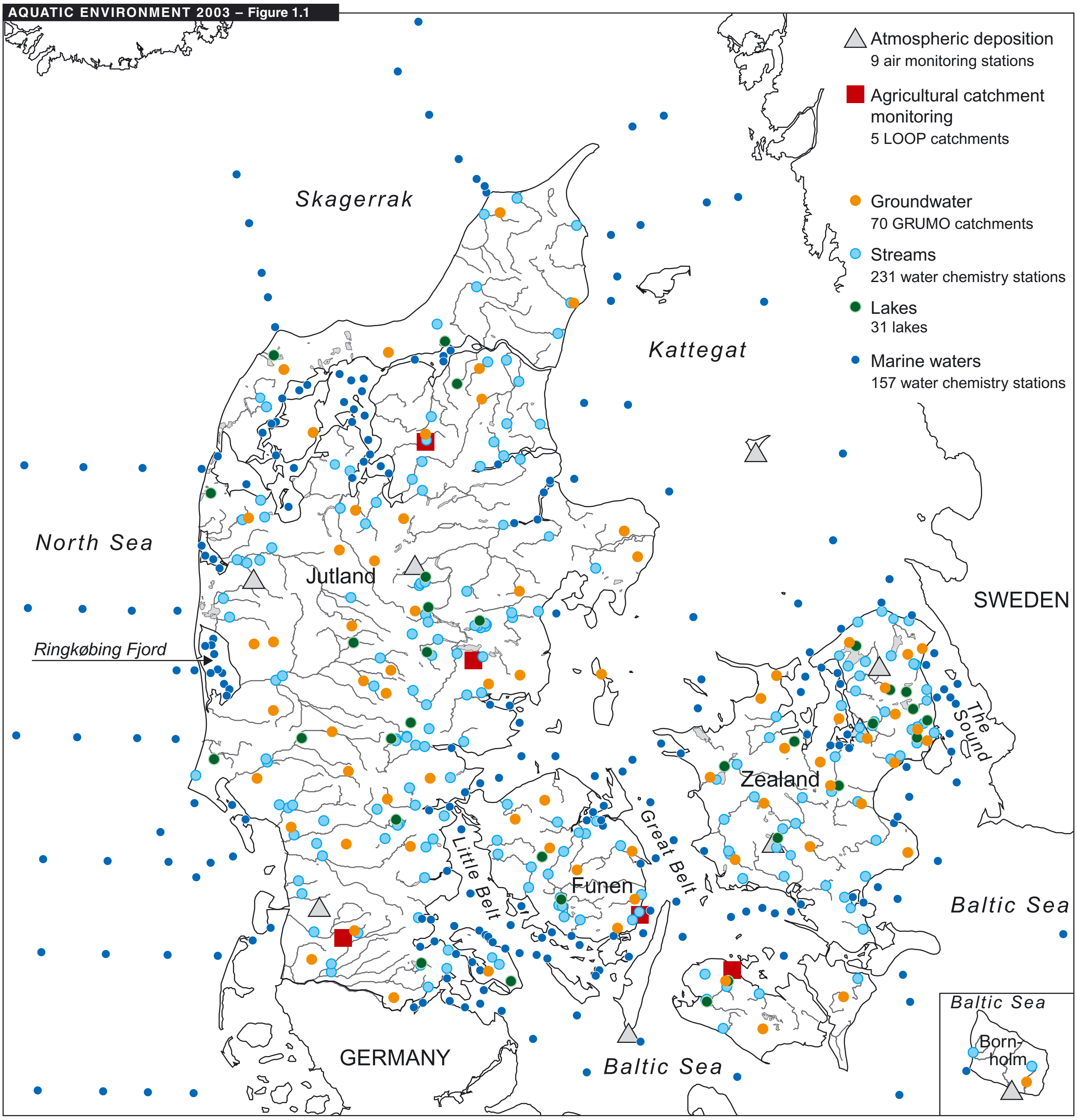


Figure 1.1 NOVA-2003 investigation localities for selected elements of the monitoring programme.

1.2 Climate and freshwater runoff

Precipitation

With a mean of 864 mm, precipitation in 2002 was 152 mm (21%) above the normal of 712 mm (table 1.1). 2002 was thus the third-most wettest year since monitoring was initiated in 1989, only surpassed by 1994 and 1999. At the national level precipitation was significantly above normal, but particularly September and December were drier than usual (figure 1.2). This annual distribution was characteristic of the whole country, except for the island of Bornholm in the Baltic Sea, where precipitation in October reached approx. 190 mm compared to the normal of approx. 65 mm.

Temperature

With 9.2 °C, 2002 was the second warmest year since regular monitoring was initiated in 1874, only 1989 with 9.3 °C has been warmer. Thus, temperature was 1.5 °C above normal (table 1.1). Until October the mean temperature of all months was between 1.3 °C (June) and 4.0 °C (August) above normal, the mean temperature thus being 2.5 °C warmer than normal. With 3.1 °C, the average temperature of winter 2001/2002 was significantly above the normal of temperature of 0.9 °C.

Freshwater runoff

Total freshwater runoff from Denmark in 2002 was approx. 18,434 million m^3, corresponding to 429 mm. The annual runoff was thus 30% above the mean runoff for the period 1971-2000 of 326 mm or about 14,000 million m^3 (table 1.1). Especially during the first quarter of the year and in November, runoff to the sea was significantly high (figure 1.2). Heavy rainfall in June and July resulted in relatively high runoff during the summer months.

Runoff conditions and precipitation were subject to large geographic variations (figure 1.3). Runoff was lowest (240-300 mm) to the southern Belt Sea, the Baltic Sea and the Sound and highest to the North Sea (450 - >500 mm). Total runoff to all marine areas in 2002 was above normal.

AQUATIC ENVIRONMENT 2003 – Table 1.1

Period	Temperature	Precipitation	Freshwater runoff	
	(°C)	(mm)	(mm)	(mill. m^3)
2002	9,2	864	429	18.400
1989-2002	8,5	737	331	14.300
Normal	7,7	712	326	14.000

Table 1.1 Annual mean temperature, precipitation and freshwater runoff in 2002 compared to the 1961-90 normal (for runoff, however, only 1971-2000). According to *Bøgestrand (ed.), 2003* and *Cappelen & Jørgensen, 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 1.2

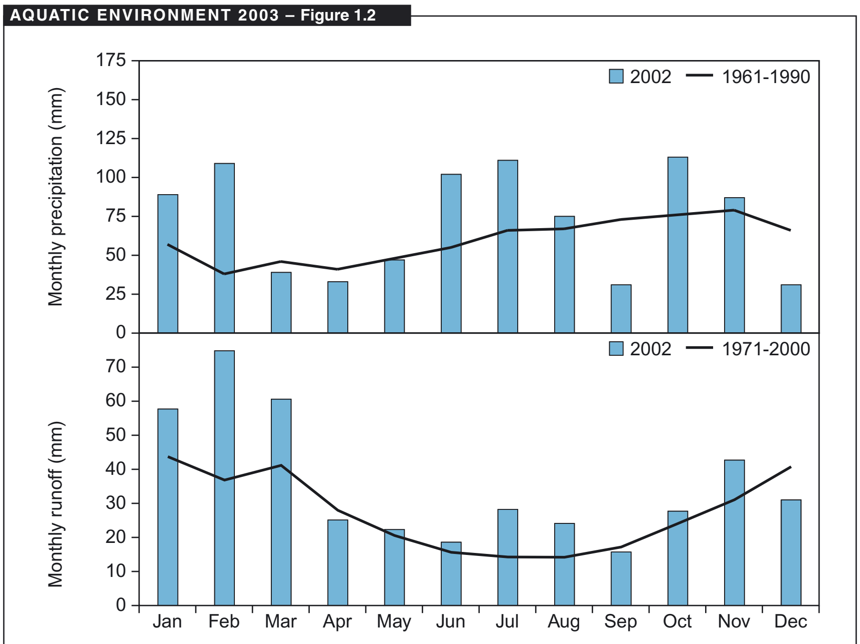


Figure 1.2 Monthly precipitation in Denmark in 2002 compared to the 1961-90 normal. Monthly mean freshwater runoff from Denmark in 2002 and mean for 1971-2000. *Bøgestrand (ed.), 2003.*

1.3 Climate development

Precipitation

On average, annual as well as winter precipitation has been higher than normal during the 14-year monitoring period. Mean annual precipitation and mean winter precipitation have thus been, respectively, 25 mm (4%) and 33 mm (16%) greater than normal.

Temperature

Of the past 15 years in Denmark, 13 have been warmer than normal (*Cappelen & Jørgensen, 2003*), and only two of the 14 monitoring years have been colder. Mean temperature during the monitoring period has been 8.5 °C compared to the normal (1961-1990) of 7.7 °C. Especially the winter temperature has been unusually high with 2.5 °C compared to the normal of 0.9 °C.

Runoff and groundwater table

The variations in runoff mimic those of precipitation with a minor delay (figure 1.4). The same applies to the groundwater table, with a longer delay, however. During dry years, groundwater aquifers are depleted and during wet years the groundwater aquifers will be filled up, as was the case in 2002. The groundwater table is now generally above the normal.

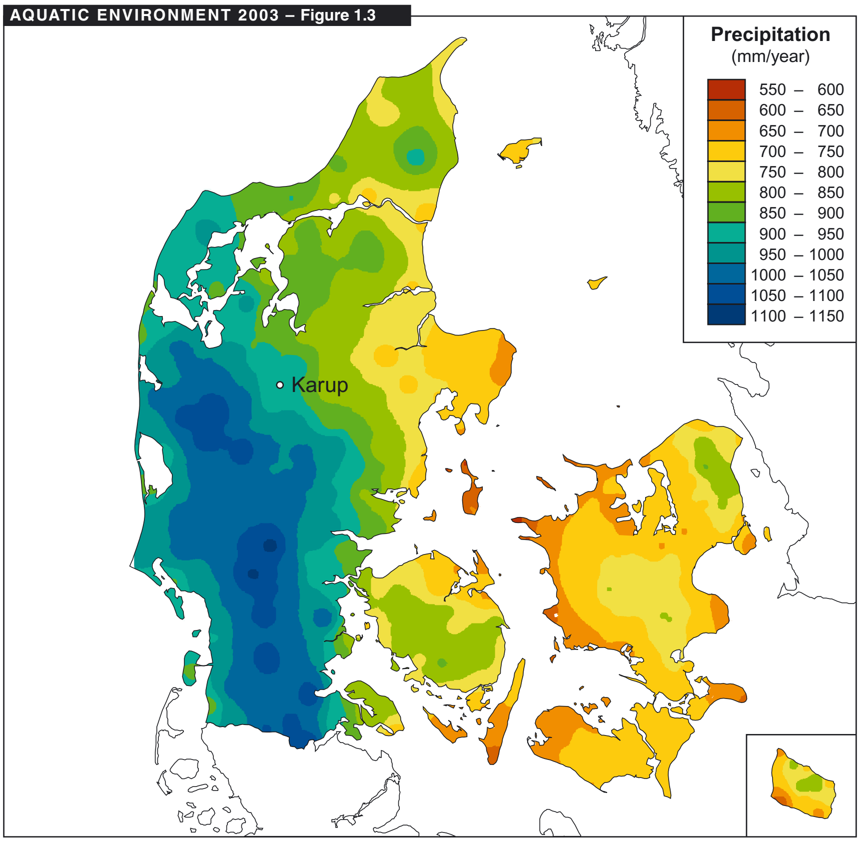


Figure 1.3 Annual mean precipitation for the period 1971-98. *Scharling, 2000.*

AQUATIC ENVIRONMENT 2003 – Figure 1.4

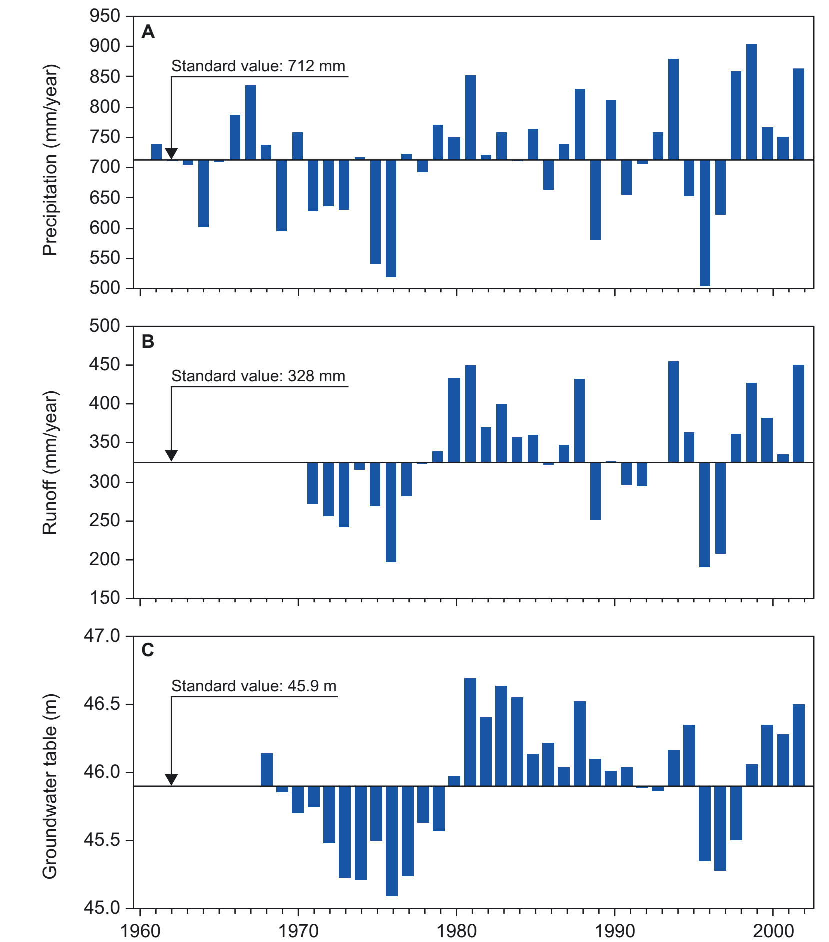


Figure 1.4 Annual mean precipitation and runoff in Denmark and annual mean groundwater level at Karup (see figure 1.3) for 1961-2002 shown relative to the 1961-90 (A), 1971-2000 (B) and 1968-90 (C) averages. *Bøgestrand (ed.), 2003* and *Cappelen & Jørgensen, 2003* and *GEUS, 2003.*

2 Pollution of water bodies with organic matter, nitrogen and phosphorus

Organic matter and nutrients occur naturally in the water bodies, including groundwater. They are a precondition for life in water, but are also the most important source of pollution of our water bodies. When the input of these substances exceeds the naturally occurring input markedly, the flora and fauna of our water bodies are affected. The sources of this pollution (eutrophication) are divided into point sources (wastewater) and diffuse sources (from cultivated fields and via the atmosphere).

2.1 Pollution from each type of source

Table 2.1 shows all the sources that contribute with organic matter, nitrogen and phosphorus to streams, lakes and marine waters. It appears from the table that there are many different and important anthropogenic sources of organic substances and phosphorus, while the predominant nitrogen sources are atmospheric inputs and leaching from cultivated fields. Input from adjoining marine waters with contributions from other countries is also important, but is not included in table 2.1.

Some of the values are only rough estimates: BOD5 input from stormwater outfalls is estimated as being half of the total content of organic matter (COD). The estimated agricultural input of BOD5 and the atmospheric phosphorus input are also very uncertain. Also the division of phosphorus input into background loss and agricultural input is subject to uncertainty.

Estimated assessment of influence of the pollution sources on stream bodies
The figures in table 2.1 illustrate the general ratios on the national level of the various sources of pollution with organic substances and nutrients, and thereby also the general significance of each type of pollution source.

However, there are two reasons why the table cannot be used to illustrate the significance of the individual pollution source for specific water bodies.

One reason is the differing sensitivity of the different categories of water bodies to inputs of these substances. Increased nitrate concentrations in a stream, for instance, would probably not affect the flora and fauna in the stream. But the same increase could involve drastic changes in marine waters or certain lakes.

Another reason is that the source apportionment for Denmark as a whole in the table will have no resemblance with the source apportionment of a specific water body. All industrial discharges are, for instance, to marine waters, while all discharges from freshwater fish farms are to streams in Jutland.

Source calculations for each individual water body are required in order to estimate the potential environmental benefits from measures against inputs of nutrients and organic substances. Calculations of potential changes in input will then enable estimations/calculations of potential effects in the water body as a result of these changes.

AQUATIC ENVIRONMENT 2003 – Table 2.1

Source apportionment 2002	Organic matter (BOD_5) (tonnes/year)	Nitrogen (tonnes/year)	Phosphorus (tonnes/year)
Natural background loss	11,100	12,700	440
Agricultural load	7,300	74,900	1,160
Wastewater treatment plants	2,670	4,528	510
Stormwater outfalls	9,000	1,006	250
Wastewater from scattered dwellings	3,800	970	220
Industry	5,913	753	50
Freshwater fish farms	3,276	1,180	94
Sea-based and land-based mariculture	1,745	307	31
Atmospheric deposition on Danish marine territory	-	107,000	400
Sources, total	**45,000**	**203,000**	**3,200**

Table 2.1 Total sum of input sources of organic substances and nutrients to water bodies in Denmark in 2002. *Danish EPA, 2003* and *Bøgestrand (ed.), 2003.*

3 Point sources

Point sources are wastewater discharges from wastewater treatment plants, industry, freshwater fish farms, scattered dwellings and stormwater outfalls and input from marine fish farms. Measurements are reported by *the Danish EPA, 2003*.

Total discharges in 2002
Total discharges from point sources in 2002 comprised approx. 20,200 tonnes organic matter (BOD_5), 8,750 tonnes nitrogen and 1,150 tonnes phosphorus. The discharges of these substances apportioned by the different point sources are shown in figure 3.1.

Municipal wastewater treatment plants are the major contributors of nutrients from point sources, but contributions from the remaining types of point sources are higher for organic matter (BOD), because all the planned measures for industry and scattered dwellings were not finally completed in 2002.

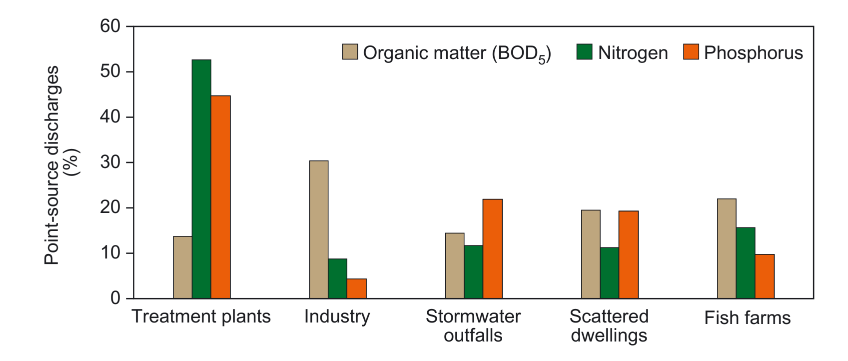
Temporal development in point sources
The total reduction in nitrogen discharges was mainly achieved because of reduced discharges from industry and wastewater treatment plants. Figure 3.2 shows the trend in nitrogen discharges from point sources, where discharges have fallen from approx. 27,600 tonnes in 1989 to approx. 8,750 tonnes in 2002.

Total phosphorus discharges from point sources have fallen from approx. 6,600 tonnes in 1989 to 1,150 tonnes in 2002. The decrease is mainly attributable to reductions in discharges from wastewater treatment plants and industry, although discharges from scattered dwellings and freshwater fish farms have also decreased (figure 3.3).

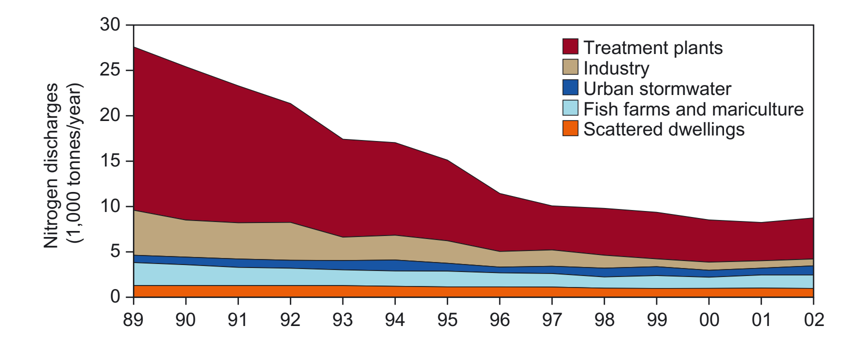
3.1 Wastewater treatment plants

In 2002 measurements and calculations were made of discharges from 1030 municipal wastewater treatment plants, of which 266 are encompassed by the treatment requirements of the Action Plan on the Aquatic Environment (minimum treatment requirements normally 15 mg BOD_5/l, 1.5 mg P/l and 8 mg N/l). These plants treat

AQUATIC ENVIRONMENT 2003 – Figure 3.1



AQUATIC ENVIRONMENT 2003 – Figure 3.2



AQUATIC ENVIRONMENT 2003 – Figure 3.3

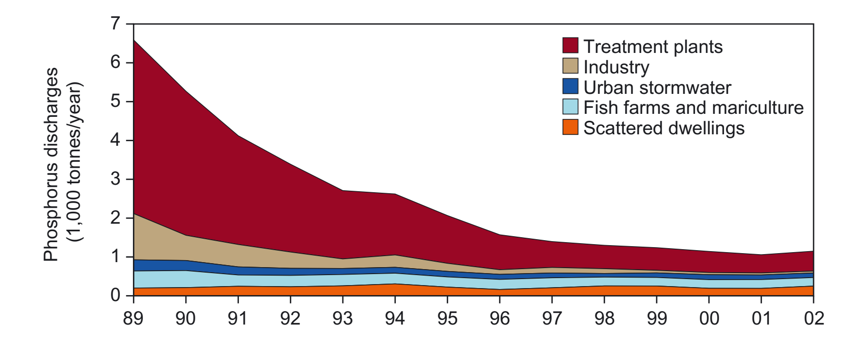


Figure 3.1 Percentage distribution of discharges of organic matter (BOD_5), nitrogen and phosphorus from 5 types of point sources in 2002. The discharges from wastewater plants and industrial discharges are the most accurate while the rest are based on estimates and therefore subject to some inaccuracy. *Danish EPA, 2003.*

Figure 3.2 Discharge of nitrogen from point sources during the period 1989-2002. *Danish EPA, 2003.*

Figure 3.3 Discharge of phosphorus from point sources during the period 1989-2002. *Danish EPA, 2003.*

approx. 93% of the total amount of urban wastewater in Denmark. The specific discharge requirements are often tightened in the interest of local, vulnerable recipients, also when it comes to plants with a capacity less than 5,000 PE (person equivalents), which is the lower limit for compliance with the general aquatic environment requirements.

Total discharge from wastewater treatment plants

Discharges in 2002 were calculated at 2,670 tonnes organic matter measured as BOD_5, 4,538 tonnes nitrogen, 510 tonnes phosphorus and 809 million m^3 wastewater. Discharges in 2002 are slightly higher than in 2001. This is probably attributable to the higher level of precipitation in 2002.

Treatment efficiency

In 2002 data are available for inputs of organic matter, nitrogen and phosphorus. By comparing data from the plants with available input data with the discharge data, the treatment efficiency of each plant has been calculated.

Figure 3.4 shows the calculated average treatment efficiency for organic matter, nitrogen and phosphorus apportioned by plant type. Treatment efficiency for plants with biological treatment and nutrient removal (MBND and MBNDC) is about 90% for all the three indicated parameters. As approx. 90% of the total amount of wastewater is treated in this type of plants, the majority of the Danish wastewater is consequently subjected to very efficient treatment.

The treatment efficiency of the remaining type of plants is as predicted. Phosphorus removal is, however, remarkably efficient in biological plants without chemical stripping (MD and MBND), mainly because many biological plants can be operated with a high degree of biological phosphorus removal.

Nutrient concentrations in the discharged wastewater of each individual treatment plant are given in Annex 1.7 B in Danish EPA, 2003. The tables there show that the treatment efficiency of the majority of treatment plants by far exceeds the general requirements of the Action Plan on the Aquatic Environment. Most plants achieve average concentrations of BOD_5 at 2-4 mg/l and phosphorus concentrations of 0.2-0.5 mg/l.

AQUATIC ENVIRONMENT 2003 – Figure 3.4

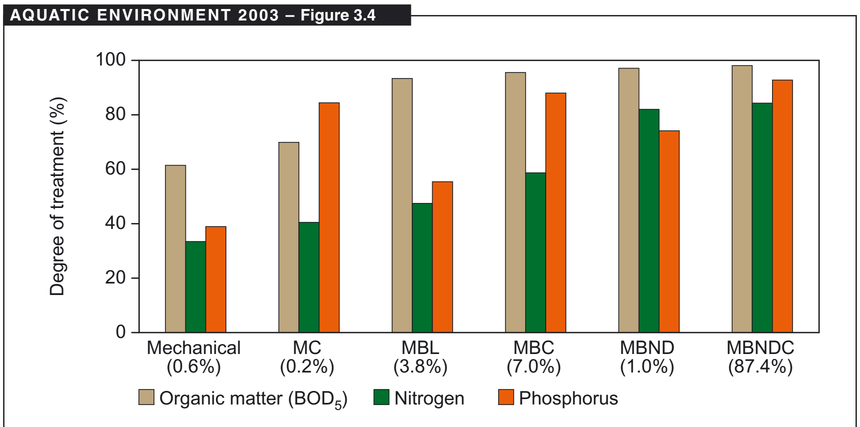


Figure 3.4 Treatment efficiency apportioned by type of treatment plant for organic matter (BOD_5), total nitrogen and total phosphorus. The amount of wastewater treated by each type of treatment plant is indicated as percentage of the total amount of wastewater. *Danish EPA, 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 3.5

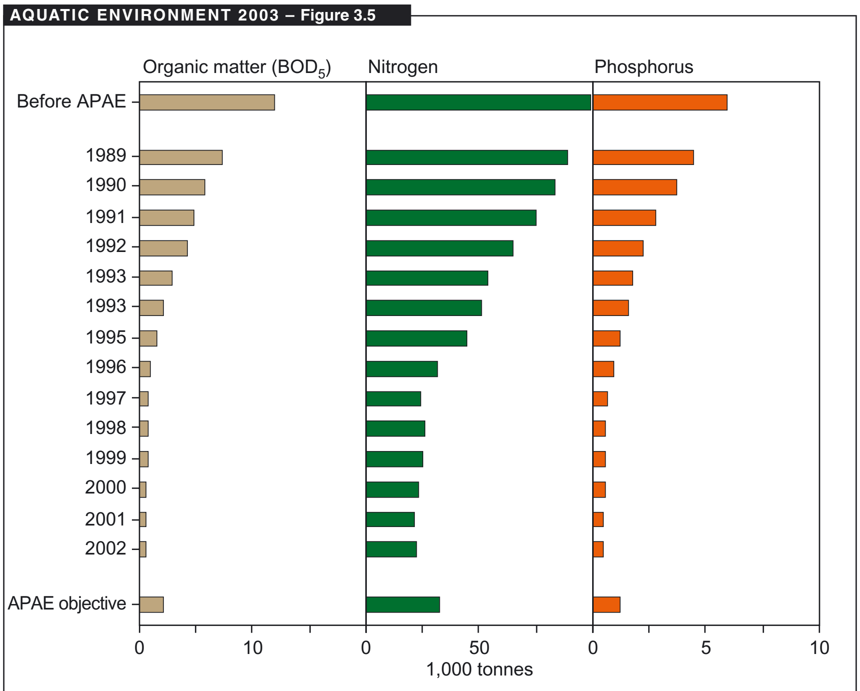


Figure 3.5 Trend in discharges from wastewater treatment plants until 2002. *Danish EPA, 2003.*

Complicance with the discharge limit values

Of the 266 plants encompassed by the Danish Action Plan on the Aquatic Environment, only one plant did not comply with the general phosphorus treatment requirement, and only two plants failed to comply with the nitrogen treatment requirement, while all plants complied with the BOD_5 requirement.

Trend in discharges

Figure 3.5 illustrates the discharge of BOD_5, nitrogen and phosphorus at the time before the implementation of the Danish Action Plan on the Aquatic Environment, in the mid-1980s, during the years 1989-2002 and finally the predicted discharge when the targets of the Danish Action Plan on the Aquatic Environment have been achieved. Particularly the discharges of BOD_5 and phosphorus as a whole are considerably below the targets of the Action Plan on the Aquatic Environment.

From the time before the implementation of the Action Plan on the Aquatic Environment, i.e. the mid-1980s, until 2001, the three parameters BOD_5, nitrogen and phosphorus have been reduced by 96%, 77% and 91%, respectively.

3.2 Industry and fish farming

In 2002, 31 industrial companies were encompassed by the requirements stipulated in the Action Plan on the Aquatic Environment of limiting the nutrient discharges. Apart from these enterprises, measurements and calculations were made of discharges from 152 other industries with separate discharges, 361 freshwater fish farms, 14 land-based mariculture farms and 25 sea-based mariculture farms. The freshwater fish farms are all situated at streams in Jutland. Land-based mariculture farms are found at the coast where salt water is pumped into the production facility, while the production in land-based takes place in net cages.

Discharges in 2002

For enterprises with direct discharges to water bodies, the highest discharges of organic matter (BOD_5) are from industries encompassed by the requirements of the Danish Action Plan on the Aquatic Environment of nutrient reduction. 80% of these discharges derive from sugar factories while 16% derive from the fishing industry.

Industrial discharges of phosphorus and nitrogen derive mainly from freshwater fish farms (table 3.1). The majority of these discharges are transported through lakes and inlets that are vulnerable towards nutrient inputs.

Trend in discharges from enterprises

Industry

Since 1989, discharges of organic matter and nutrients from separate industrial dischargers have declined markedly. BOD_5 has decreased by 89% , nitrogen discharges by 88% and phosphorus discharges by 96%. The majority of these reductions are a result of environmentally improved production methods and improved wastewater treatment at the enterprises. A considerable part of the reduction is, however, a result of the wastewater being led to a municipal treatment plant, or the closing down of the enterprise.

Figure 3.6 illustrates the trend in the total industrial discharges for the period 1989-2002. Contrary to the municipal treatment plants there are no predetermined reduction targets for the total industrial discharges.

Freshwater fish farms and mariculture

Discharges from freshwater fish farms, land-based and sea-based mariculture farms have also declined since 1989, although to a much smaller extent than discharges from the other enterprises. The estimated reduction in discharges from freshwater fish farms is approx. 50% for BOD5, approx. 60% for phosphorus and approx. 45% for nitrogen. Discharges from the land-based and sea-based mariculture farms have also decreased, but to a smaller extent than for freshwater fish farms.

3.3 Discharges from scattered dwellings

Discharges from dwellings that have no sewerage system and are not connected to a private common treatment plant, constitute a considerable load to many lakes and small streams, although the contribution is minor on a nationwide level (table 2.1 and figure 3.1). The regional reports by the county authorities establish the areas where further treatment of wastewater from scattered dwellings is required in order to achieve the environmental objectives established for water bodies. Of the approx. 354,000 dwellings not connected to a sewerage system, approx. 101,000 dwellings must improve their wastewater treatment.

AQUATIC ENVIRONMENT 2003 – Table 3.1

Enterprises 2002	Organic matter (BOD_5) (tonnes/year)	Nitrogen (tonnes/year)	Phosphorus (tonnes/year)
Industry encompassed by Action Plan on the Aquatic Environment	5,420	502	41
Industry not encompassed by Action Plan on the Aquatic Environment	493	251	9
Freshwater fish farms	3,276	1,180	94
Land-based mariculture farms	159	65	5
Sea-based mariculture farms	1,586	242	26
Total discharges from enterprises	**10,934**	**2,240**	**175**

Table 3.1 Discharges of organic matter and nutrients from industry and fish farms in 2002. *Danish EPA, 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 3.6

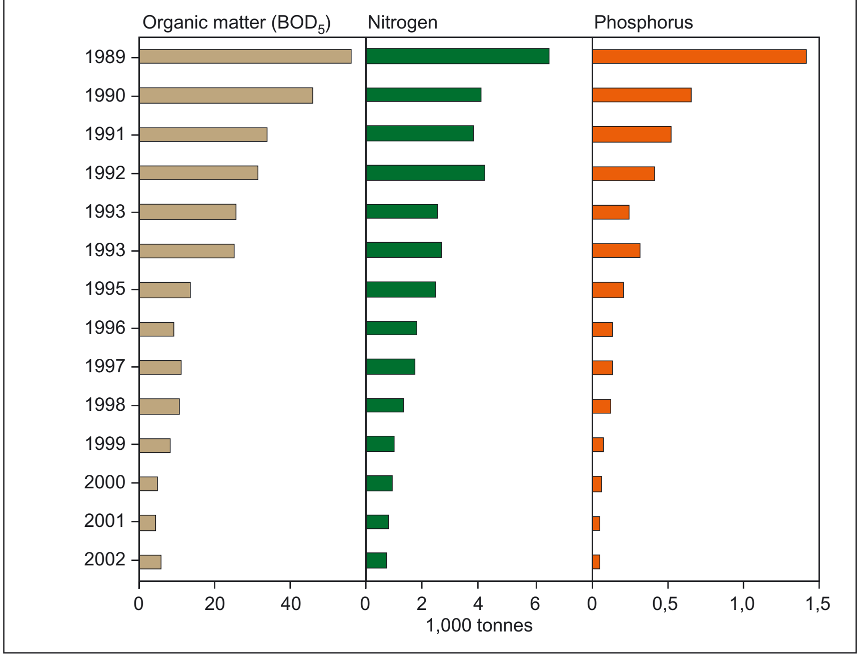


Figure 3.6 Trend in discharges of organic matter (BOD_5), nitrogen and phosphorus from separate industrial dischargers. *Danish EPA, 2003.*

4 Diffuse sources – leaching from farmland

Leaching of nitrogen and phosphorus from cultivated areas is the primary cause of eutrophication of Danish water bodies. Calculations of nutrient leaching are mainly based on monitoring in the agricultural monitoring catchments ad on monitoring of nutrient transport in streams (see figure 1.1). The monitoring results are combined with information of agricultural practices, including fertilizing practices (*Grant et al., 2003*).

4.1 Fertilizer consumption in Denmark

The consumption of commercial fertilizer has fallen markedly since 1989 with regard to both nitrogen (from 392,000 tonnes in 1985 to 206,000 tonnes in 2002) and phosphorus (from 47,800 tonnes to 13,800 tonnes in 2002). The amount of nutrients removed from the fields with harvested crops varies with the crop yield, but has remained almost constant during this period. The overall net nitrogen surplus on the fields has been reduced from 420,000 tones in 1985 to 234,000 tonnes in 2002 (figure 4.1) and the phosphorus surplus has fallen correspondingly from 54,000 tonnes in 1985 to 28,000 tonnes in 2002 (figure 4.2). Especially for phosphorus, the average surplus per hectare (table 4.1) is far higher than the amount of leached phosphorus from the areas. Consequently, phosphorus accumulates in the soil.

Revised calculation of nitrogen leaching on the national level

In November 2003, the National Environmental Research Institute and the Danish Institute of Agricultural Sciences made a new calculation of nitrogen leaching on the national level back in time. The new calculations were made because the content of nitrogen in livestock manure has been underestimated and because new and improved water balances are available. The new calculations show that nitrogen leaching in the mid-1980s was approx. 310,000 tonnes nitrogen which is considerably higher than the 260,000 tonnes on which the Action Plans on the Aquatic Environment are based. (*Grant & Waagepetersen, 2003*).

Phosphorus surplus

The average net phosphorus input to the fields in the agricultural monitoring catchments during the period 1991-2002 was approx. 8 kg P/hectare per year. During the same period, the phosphorus loss to streams was 0.38 kg P/hectare per year. Consequently, only a small part of the net input is lost to surface water. The remaining part is accumulated in the soil or it may leach to the deeper soil layers. Table 4.1 shows the figures for the country as a whole.

AQUATIC ENVIRONMENT 2003 – Figure 4.1

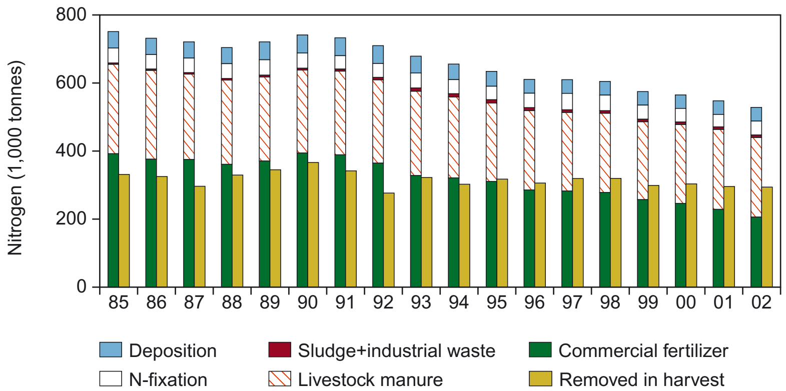


Figure 4.1 Trend in assigned nitrogen and harvested nitrogen for the total Danish agricultural land during the period 1985-2002. *Grant et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 4.2

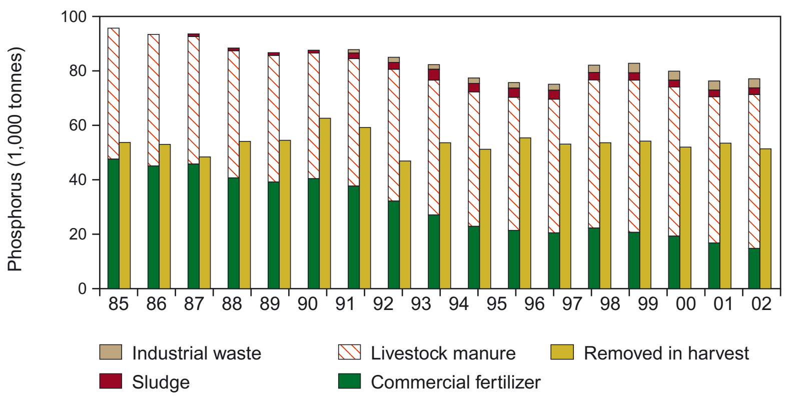


Figure 4.2 Trend in assigned phosphorus and harvested phosphorus for the total Danish agricultural land during the period 1985-2002. *Grant et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Table 4.1

N and P balance 2002	Nitrogen (kg N/ha per year)	Phosphorus (kg P/ha per year)
Fertilizer applied	198.2	28.5
Removed with harvest	110.3	18.0
Nutrient surplus	87.8	10,6
Nutrient loss	50-100	0.2-1

Table 4.1 Nitrogen and phosphorus balances for the entire cultivated area of Denmark. *Grant et al., 2003.*

The magnitude of the accumulated phosphorus surplus in the soil is strongly influenced by the agricultural practices. In pure crop farms there is a balance between fertilization and harvest, while the phosphorus surplus is high in farms with many livestock. The surplus is attributable to the use of livestock manure for nitrogen fertilization of crops. Because the phosphorus level in livestock manure is relatively higher in relation to the nitrogen content required by the plants, the phosphorus input consequently exceeds the amount required by the crop.

Input of surplus phosphorus to cultivated areas is an environmental problem because it results in an increased input of phosphorus to the water bodies. The increase is caused by higher levels of phosphorus in the erosion material from fields and by the increase in phosphorus concentrations in soil water, leading to an increase in leaching of dissolved phosphorus. A particular high increase in leaching is seen if the phosphorus-binding capacity is exceeded.

4.2 Nitrogen leaching

Fertilizer inputs and land use have been compiled calculated for 5 agricultural monitoring catchments, and leaching from the root zone towards groundwater and to drains as well as nutrient transport in the streams have been measured. In combination with model calculations of the hydrological cycle, these measurements have resulted in the description of nutrient transport through agricultural land illustrated in figure 4.3.

The modelled calculation of the annual nitrogen leaching from the root zone is 52 kg N/hectare on clayey soils and 96 kg N/hectare on sandy soils. Leaching from clayey soil is somewhat lower than the net input (difference between input with fertilizer and removal with crop), while leaching from sandy soils almost equals the net input. Leaching from sandy soils is much higher than leaching from clayey soils. In spite of this, nitrogen transport in the streams is much higher in clayey catchments (21 kg N/hectare) than in sandy catchments (7 and 16 kg N/hectare, respectively, for the two catchment types). The reason is that the leakage from clayey soils is mainly from the upper soil layer, while leakage from sandy soils mainly takes place through the deeper soil layer where it may have passed through oxygen-free areas, with considerable denitrification as a result.

Only part of the nitrogen leaving the root zone will reach the streams. The magnitude of this part of nitrogen varies greatly and depends on the local conditions. Nitrogen may also be transported through groundwater to downstream stream reaches and a long transport time through groundwater is likely to enhance denitrification.

Annual nitrogen leaching from uncultivated rural areas is approx. 12 kg N/hectare, and the transport to streams is approx. 2-3 kg N/hectare.

Total nitrogen leaching to Danish streams in 2002 is calculated at 87,600 tonnes. The natural background loss from the total Danish land is estimated at 12,700 tonnes of this amount (table 8.1, *Bøgestrand (ed.), 2003*).

AQUATIC ENVIRONMENT 2003 – Figure 4.3

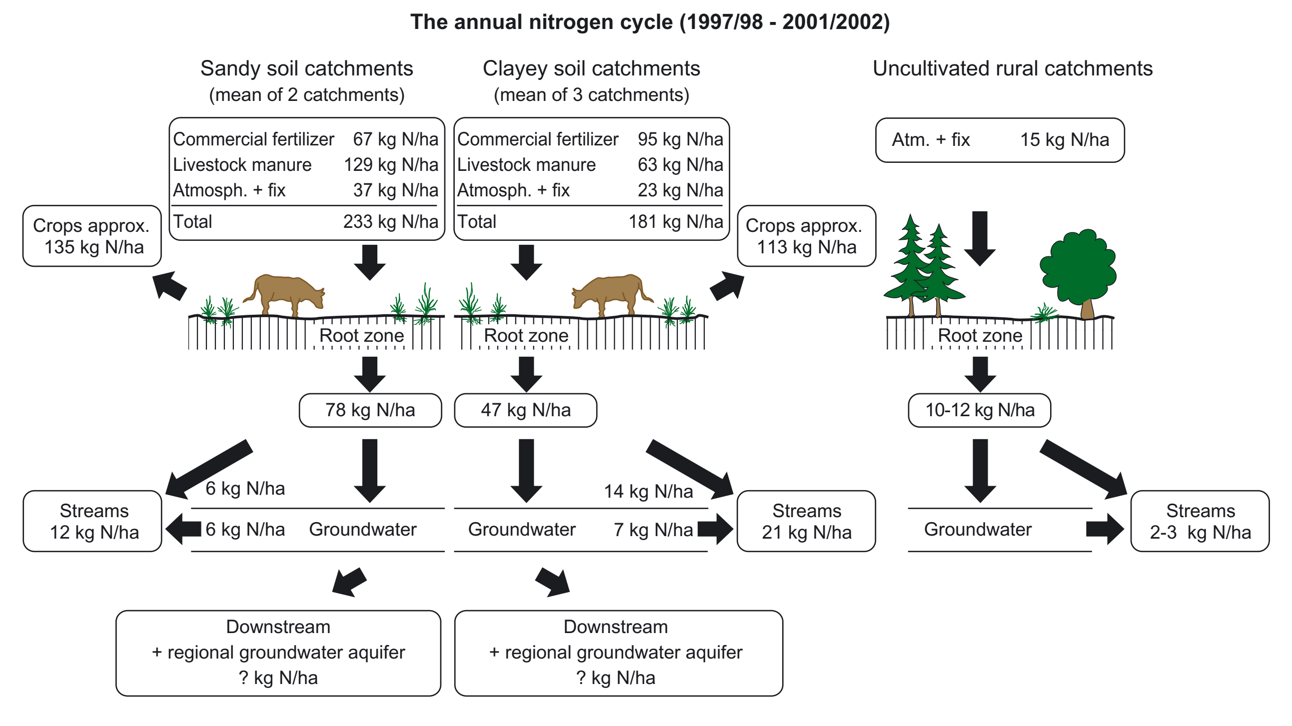


Figure 4.3 Schematic outline of the nitrogen cycle in clayey, sandy and uncultivated catchments for the period 1997/98-2001/02. *Grant et al., 2003.*

4.3 Achieved effect of the Danish action plans on the aquatic environment

Trend in leaching of nitrogen from the soil

The trend in nitrogen concentrations in water from the root zone, the upper groundwater and in streams in the LOOP areas is illustrated in figure 4.4. The figure shows a marked reduction in nitrogen concentrations in the root zone in sandy areas and a slight reduction in the upper groundwater. The changes in clayey areas are considerably less significant and more uncertain.

In table 4.2 changes in the nitrogen consumption and transports in agriculture from 1990-2002 are compared. During this period the consumption of commercial fertilizer and the nitrogen surplus on cultivated fields for the country as a whole were reduced by 48% and 38%, respectively. Calculations show a reduction in leaching from the root zone of 41%. This figure is supported by measurements of water from the root zone. In streams in agricultural catchment types, the nitrogen transport is reduced by 31% (*Bøgestrand (ed.), 2003*).

When estimating nitrogen transports in the hydrological cycle it should be noted that:

- The modelled calculation of nitrogen leaching reflects the long-term effects, i.e. the effect after many years of changed fertilization practices when an approximate equilibrium in the soil has been achieved.
- The flow of the water in the hydrological cycle results in a time delay from the time the water leaves the root zone until it reaches the streams. This time delay is considerably longer on sandy soils than on clayey soils.
- Compliance with the targets of the action plans on the aquatic environment of a 50% reduction of N-leaching will not result in a corresponding reduction in nitrogen concentrations and nitrogen transport in the streams, because the natural background concentration in streams of approx. 1 mg N/l from both cultivated and uncultivated catchment will remain the same and because part of the leached nitrate will be removed from the water because it is denitrified before reaching the streams.

On its way towards the open sea, part of the nitrate in the water is sedimented or denitrified in lakes and fjords. Concurrently with the nitrate input being reduced, the denitrification in lakes and fjords will also be reduced. However, it may be that denitrification expressed in percentages of the added nitrate amount will remain approximately the same in lakes and fjords.

AQUATIC ENVIRONMENT 2003 – Table 4.2

Amounts of fertilizer and losses	1990	2002	Reduction
Commercial fertilizer applied (tonnes N/year)	395,000	206,000	48%
Nitrogen surplus (tonnes N/year)	375,000	234,000	38%
Model calculated average loss (kg N/ha per year)	107	70	41%
Monitored average concentration of nitrogen in root-zone water in agricultural catchments			
Clayey soil (mg N/l)	22	14	32% (11-50%)
Sandy soil (mg N/l)	34	18	47% (34-61%)
Streams in agricultural catchments[1]			31% (27-35%)

[1] *Bøgestrand (ed.), 2003.*

Table 4.2 Reduction in nitrogen consumption and transports in agriculture 1990-2002. *Grant et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 4.4

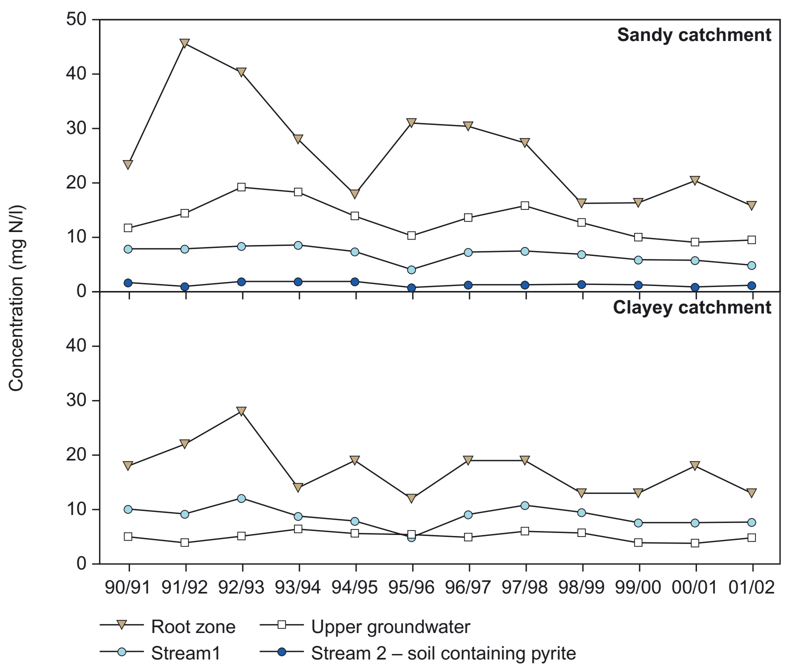


Figure 4.4 Trend in nitrogen concentrations for the period 1999/01-2001/02 in water from the root zone, the upper groundwater and streams in 3 clayey catchments and 2 sandy catchments. *Grant et al., 2003.*

4.4 Leaching of phosphorus from the soil

Phosphorus loss from clayey soils to drains

Examples of the annual loss of dissolved and total phosphorus (P) to drains, and the annual flow-weighted concentrations of P are illustrated in figure 4.5. The difference between total-P and dissolved P is particulate P and/or organic P. Measurements reveal significant variations in P-leaching, depending especially on the water runoff. Measurements also reveal very high phosphorus concentrations in drains from certain fields, in most incidents around 0.2 mg P/l (right section of figure 4.5).

During the monitoring period transport of total phosphorus via drains was 0.054 kg P/hectare per year, of which dissolved P constituted approx. 45%. Particulate P consequently represented a substantial share of the P-loss from drains on sandy soils; this was especially the case in LOOP 4 (Lillebæk stream on Funen).

At one of the monitoring stations (no. 106 in LOOP 1, Højvads Rende on the island of Lolland) the average concentrations of total-P was 0.220 mg P/l and leaching was an average 0.206 kg P/hectare per year, of which ortho-P constituted 91%. The large P-loss from this soil may be due to a very high phosphorus index in the topsoil (P_t=10.7).

Phosphorus loss from cultivated areas is mainly controlled by the level of precipitation, and consequently the runoff during the individual monitoring years. In relation to the five streams it is possible to establish connections between the annual runoff and the annual loss of total phosphorus from agricultural areas in the catchment within the hydrological year (figure 4.6). The annual phosphorus loss from agricultural areas increases in the individual catchments with increasing runoff. At increasing runoff, the highest increase in phosphorus loss is from the clayey Lillebæk stream catchment, and the lowest increase is from the sandy catchment of Bolbro stream, where the surface runoff is low.

AQUATIC ENVIRONMENT 2003 – Figure 4.5

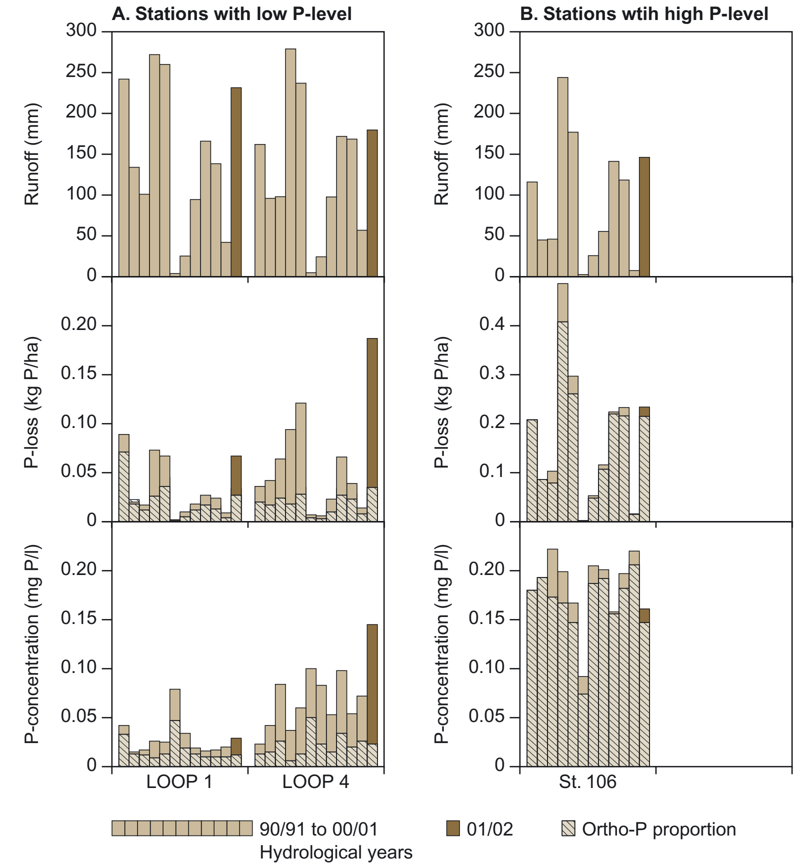


Figure 4.5 Annual runoff and P loss from drains, and flow-weighted P concentrations in drain-water as an average for the monitoring stations in two clayey catchments for the period 1990/91-2001/02. The columns illustrate total P while the shaded area of the columns illustrates ortho-P. A: stations with low P level, B: station with high P level. *Grant et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 4.6

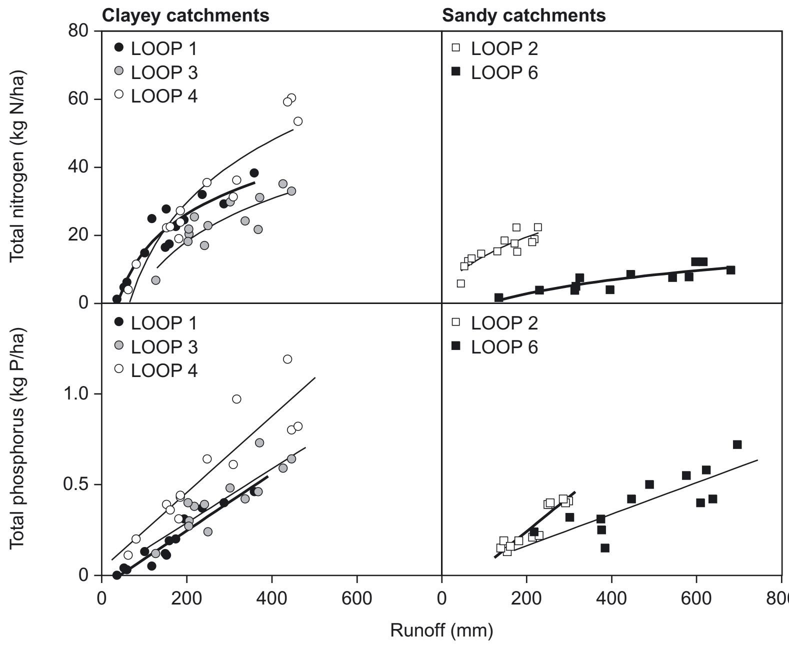


Figure 4.6 Relations between the annual losses of nitrogen and phosphorus from cultivated field and the flow of water from five small catchments (LOOP) during the period 1989/90 to 2001/02. 1: Højvads Rende, 2: Odderbæk Stream, 3: Horndrup Stream, 4: Lillebæk Stream, 6: Bolbro Stream. *Grant et al., 2003.*

5 Diffuse sources – the atmosphere

The atmospheric input of nitrogen compounds contributes considerably to the eutrophication of the open marine waters and of uncultivated areas and some lakes. Other atmospheric inputs of pollutants to water bodies are usually less significant.

Monitoring programme and model calculations

The atmospheric monitoring programme comprises 9 monitoring stations distributed throughout Denmark (see figure 1.1).

Monitoring at these stations includes:

- Wet deposition (concentrations in precipitation) of nitrogen compounds, sulphate, phosphate and metals
- Atmospheric concentrations of nitrogen compounds, sulphur compounds, phosphate and metals.

On the basis of these measurements and the knowledge of pollutants and the meteorological conditions, the so-called ACDEP model is employed to calculate nationwide values describing atmospheric concentrations and depositions. The calculated results are indicated for each quadrate of a 40x40 km network covering both the Danish land area and the Danish marine territory (*Ellermann et al., 2003*).

5.1 Phosphorus deposition

Compared to other sources, phosphorus deposition from the atmosphere is low, but it is very difficult to measure. On the basis of monitoring results of NERI and Funen County, *Ellermann et al., 2003* estimate that the deposition of inorganic phosphorus to the inner Danish marine waters (31,500 km2) is 4 kg P/ km2 per year or a total of 130 tonnes P/year. This corresponds to 400 tonnes P/year for the entire Danish marine territory. Deposition of organic phosphorus could be of the same order of magnitude. A temporal development in the deposition of phosphorus is unlikely.

5.2 Nitrogen compounds in the air

Annual mean concentrations of atmospheric ammonia measured at the monitoring stations exhibit significant geographical differences in the atmospheric ammonia content (table 5.1). This is attributable to the fact that the greater part of the ammonia content of the air derives from evaporation from livestock manure and that ammonia stays in the atmosphere for a short period (hours), i.e. a quick chemical conversion and deposition on plants, soil etc. takes place. In contrast, the concentrations of the remaining nitrogen compounds that are dispersed over great distances through the atmosphere are more uniform because they stay in the atmosphere for longer periods (days). Nitrate and nitrogen oxides mainly derive from combustion processes.

Nitrogen deposition at the monitoring stations

The measured nitrogen depositions on land are generally between 1.5 and 2 tonnes N/km^2 per year. Dry deposition is far greater on land than on water surfaces because of the shorter distance to the sources and because nitrogen compounds dry deposit quicker on plants and soil than on water surfaces (tables 5.2 and 5.3). The tables also indicate that depositions are higher in areas with many livestock (Lindet and Tange). High precipitation also contributes to increased nitrogen depositions.

AQUATIC ENVIRONMENT 2003 – Table 5.1

Annual mean conc. (µg N/m^3)	Ammonia	Ammonium	Sum-nitrate	Nitrogen dioxide
Anholt	0.17	1.13	0.79	1.82
Frederiksborg	0.27	1.25	0.75	-
Keldsnor	0.81	1.90	1.22	2.81
Lindet	1.43	1.87	1.17	-
Tange	1.11	1.53	0.86	-
Ulborg	0.41	1.06	0.64	1.51
Lille Valby	-	-	-	3.64

Table 5.1 Content of nitrogen compounds in the air at six main monitoring stations and Lille Valby in 2003. *Ellerman et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Table 5.2

Annual deposition – water (kg N/km^2)	Dry deposition	Wet deposition	Total deposition	Wet deposition (%)
Anholt	79	713	792	90
Keldsnor	240	771	1,011	76
Tange	260	1,012	1,272	80

Table 5.2 Dry deposition, wet deposition and total deposition of nitrogen to water surfaces at the monitoring stations in 2002. *Ellermann et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Table 5.3

Annual deposition – land (kg N/km^2)	Dry deposition	Wet deposition	Total deposition	Wet deposition (%)
Anholt	413	713	1,126	63
Frederiksberg	622	762	1,384	55
Keldsnor	922	771	1,693	46
Lindet	1,198	1,071	2,269	47
Tange	879	1,012	1,891	54
Ulborg	471	611	1,082	56

Table 5.3 Dry deposition, wet deposition and total deposition of nitrogen to land surfaces at the monitoring stations in 2002 (dry deposition is calculated for land surface with 10 cm tall grass). *Ellermann et al., 2003.*

5.3 Calculated nitrogen deposition from the atmosphere

Deposition on marine waters

Model calculations reveal that the typical nitrogen deposition on Danish marine waters is between approx. 0.7 and 1.6 tonnes N/km² per year (figure 5.1). The highest deposition in open marine waters is in the Little Belt with approx. 1.5 tonnes N/km² per year. The lowest deposition is in the Skagerrak (0.8 tonnes N/km² per year). The southern part of the Danish section of the North Sea exhibits higher contents that derive from the countries situated southwest of Denmark. The calculated total nitrogen deposition on Danish marine waters (105,372 km²) of 107.000 tonnes N in 2002 is approx. 9% less than that reported for 2001. Approx. 14% of the nitrogen deposition on marine waters derives from Danish sources. The largest share of 28% is found in the Belt Sea (see source apportionment for the Kattegat in figure 2.13 in *Ellermann et al., 2003*).

Deposition on land areas

The calculated total nitrogen deposition on Danish land areas is approx. 80,000 tonnes N in 2002 (figure 5.2). The total deposition on land areas (typically about 1.8 tonnes/km²) in Denmark is higher than that on marine waters ((typically around 1.0 tonnes N/km²). The reasons for the variations are:

- Land areas are in closer proximity to the source areas and the turbulence and consequently dry deposition rate to land areas are generally slightly higher than that on the sea
- Nitrogen dioxide dry deposits on plants on land while it is generally not dissolved in water and therefore does not deposit on water surfaces
- Precipitation is usually higher over land than over the sea.

AQUATIC ENVIRONMENT 2003 – Figure 5.1

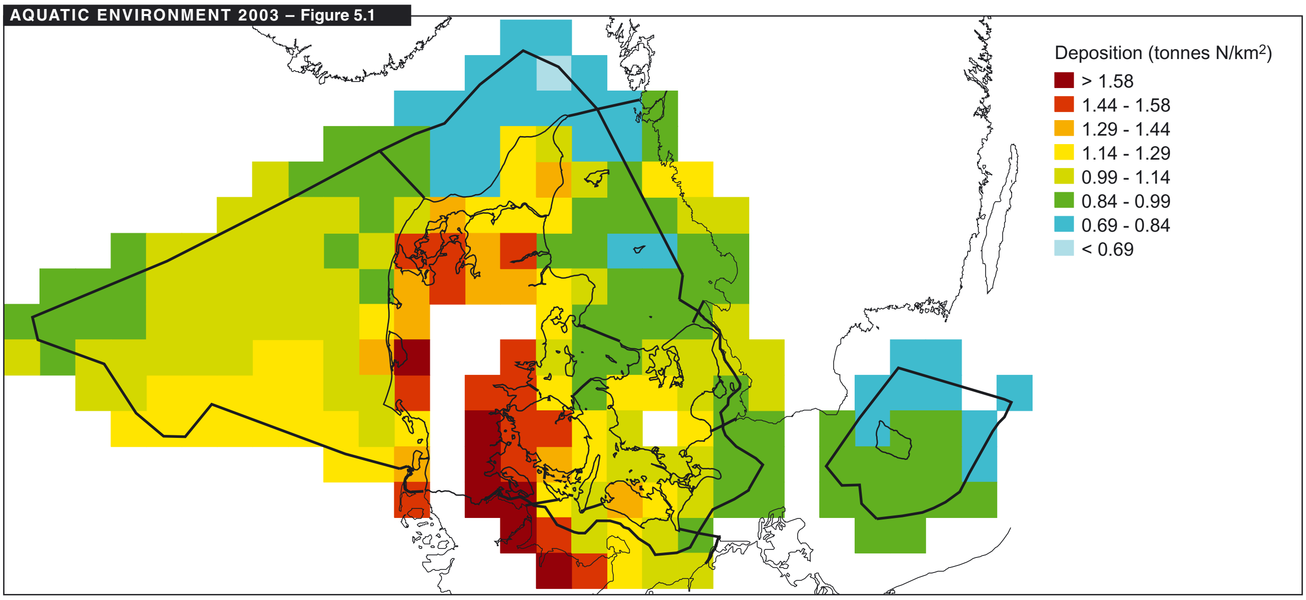


Figure 5.1 Total deposition (dry + wet) of nitrogen compounds to marine areas calculated for 2002. Deposition is indicated in tonnes N/km². Deposition only applies to water surfaces in the different fields. *Ellermann et al., 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 5.2

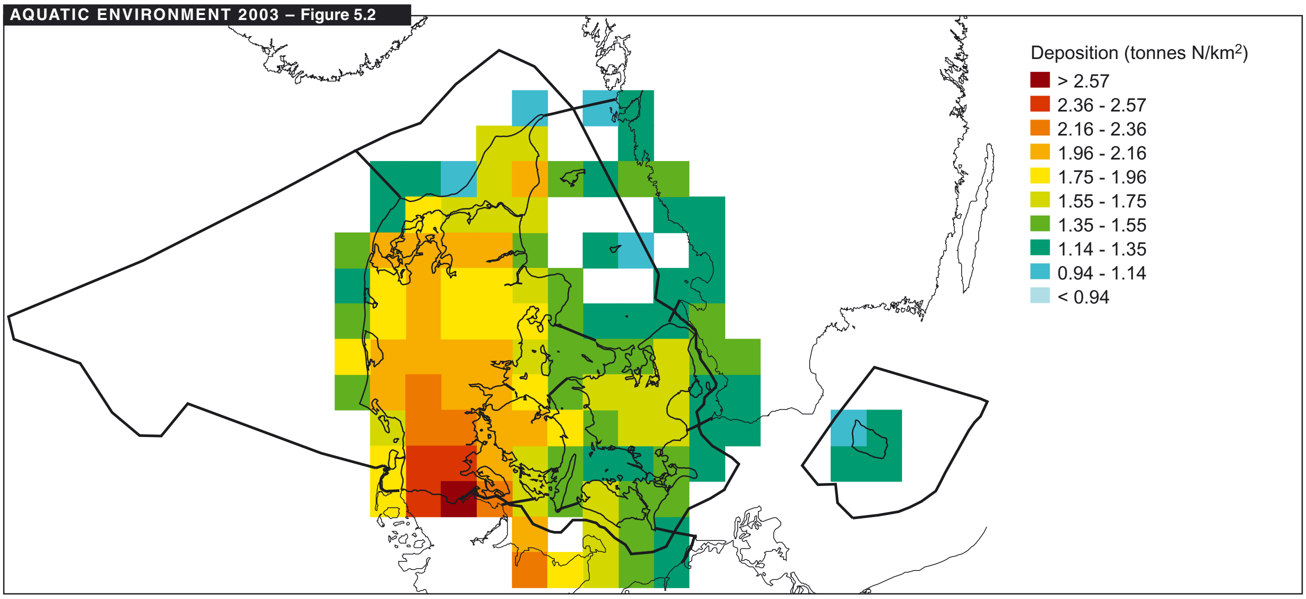


Figure 5.2 Total deposition (dry + wet) of nitrogen compounds to land surfaces calculated for 2002. Deposition is indicated in tonnes N/km². Deposition only applies to land surfaces in the different fields. *Ellermann et al., 2003*.

5.4 Trend in nitrogen deposition from the atmosphere

A slight decrease of approx. 17% in the total deposition of nitrogen – the sum of wet deposition and dry deposition – is estimated for the period 1989-2002 when the deposition to water surfaces and means of the monitoring results (the decrease at a few of the monitoring stations is not significant) are considered. The moderate changes are presumably attributable to two factors counteracting the decrease in the depositions (figure 5.3).

The most important factor is the changes in the level of precipitation, which result in marked year-to-year fluctuations of the wet deposition. The three wet years in 1998-2000 have resulted in increased levels of precipitation in several of the monitoring stations, which has counteracted a potential decrease in wet deposition. The other factor is that a fall in the atmospheric content of sulphur compounds probably has resulted in a slower conversion of ammonia in the atmosphere, and that ammonia concentrations therefore have fallen less than would have been expected on the basis of the reduction in the emissions

Sources of nitrogen deposition

The nitrogen compounds are all related to two major sources:

- Agriculture, which accounts for more than 95% of the total ammonia emissions.
- Combustion processes (cars, power plants, industrial combustion, domestic heating, ship traffic, etc.) which emit more than 95% of the total amount of nitric oxides.

Monitoring results and model calculations both indicate that 36-63% of nitrogen depositions derive from ammonia compounds, and consequently from agriculture. The largest share of ammonia is found in areas in Jutland with large livestock herds while the smallest share is in areas far from agriculture, e.g. the island of Anholt in the Kattegat and the northern part of Zealand.

Model calculations have furthermore made it possible to estimate the load from Danish sources. Calculations indicate that Danish sources constitute approx. 38% and 13%, respectively, of the depositions to land surfaces and water surfaces.

AQUATIC ENVIRONMENT 2003 – Figure 5.3

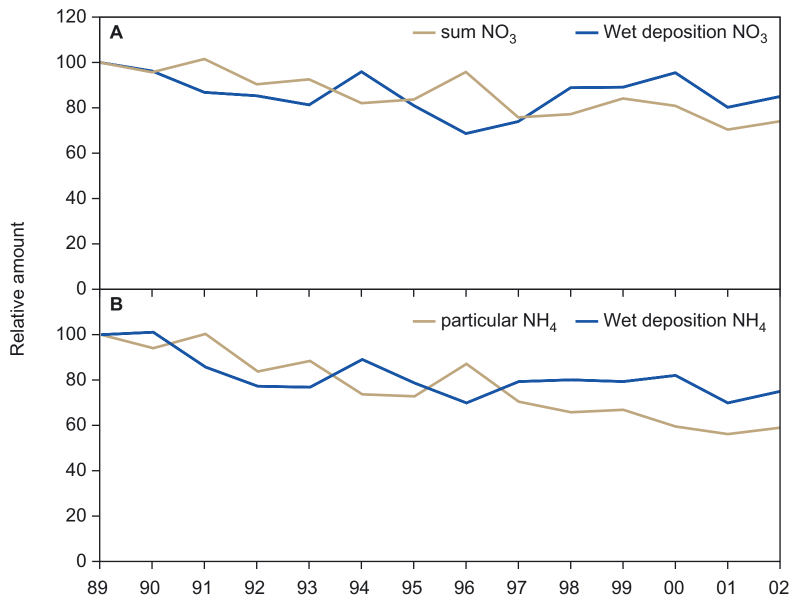


Figure 5.3 Relative variations in wet deposition or concentrations of nitrogen compounds. Ammonia in the lower part of the figure and NO_x in the upper part (average for monitoring stations). *Ellermann et al., 2003.*

6 Groundwater

Pollution of groundwater is primarily caused by increased nitrate concentrations consequent to cultivation. When the groundwater is used as drinking water this could pose a health concern, and nitrate-containing groundwater may, when reaching the surface water, contribute to the eutrophication of lakes and marine areas. Moreover, the groundwater may contain pesticides and other environmental pollutants, making it unsuitable for use as drinking water.

The groundwater monitoring programme

The most important part of the groundwater monitoring programme is the 70 groundwater monitoring areas (GRUMO) that are distributed evenly throughout the country (figure 1.1).

The groundwater monitoring also includes approx. 85 intakes in the upper groundwater aquifers in 5 agricultural monitoring areas (LOOP), in which, among other parameters, the quality of the newly formed groundwater below cultivated fields is analysed.

Finally, data from the waterworks well controls are included in the annual report on the groundwater quality (*GEUS, 2003*).

6.1 Groundwater resources

The water supply to the groundwater aquifers is mainly determined by the amount of winter precipitation. Not only 2002, but also the years before, were rich in precipitation, varying between 743 and 905 mm for the country as a whole compared to a normal precipitation of 712 mm.

Groundwater abstraction

Total groundwater abstraction in Denmark 2002 was 653 million m^3. In comparison, total runoff to the sea was approx. 18,400 million m^3. Of the total volume abstracted for public water supply 98% comes from groundwater. Figure 6.1. shows that abstraction is mostly performed by the waterworks.

Development in groundwater abstraction

Figure 6.2 shows water abstraction divided into four main categories for the period 1989-2002. Surface water used for freshwater fish farming and cooling water purposes is not included.

Groundwater abstraction for field irrigation was particularly intensive in the counties of Ringkjøbing and Ribe, constituting in 2002 61% and 39%, respectively, of the total water abstraction in the two counties. In 2002, 26% of total water abstraction in the county of northern Jutland was used for fish farming.

In 2002, a total of 410 million m^3 was abstracted by the waterworks compared to 640 million m^3 in 1989. The abstraction for field irrigation was 158 million m3 in 2002, which is the lowest level recorded during the monitoring period.

The decline in waterworks abstraction stagnated in 2002 compared to the previous years. For the 1989-2002 period as a whole, the abstraction by waterworks decreased with 36%, while total groundwater abstraction decreased with 37% during the same period.

The water volume used for field irrigation and market gardens was substantially lower during the past 5-year period than during 1989-1997. This owes to the higher and timely precipitation during the watering season from May to June in recent years.

AQUATIC ENVIRONMENT 2003 – Figure 6.1

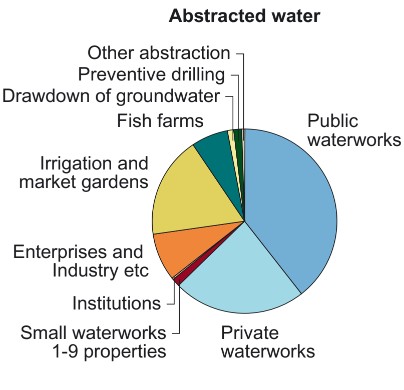


Figure 6.1 Volume of abstracted water in Denmark in 2002 divided into 10 abstraction categories. *GEUS, 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 6.2

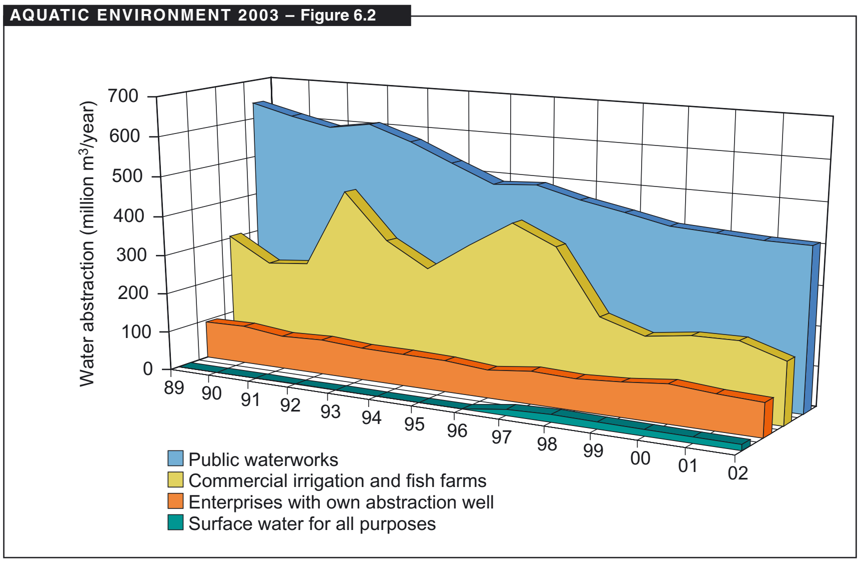


Figure 6.2 Water abstraction in Denmark (mill m^3/year) for the period 1989-2002. Data on abstraction of surface water not available until 1997. *GEUS, 2003*.

The groundwater table

During the 1989-2002 monitoring period, great variations occurred in the groundwater table during 1994 and again in 2000-2002. The heavy precipitation in January, and in particular in February 2002 (the normal precipitation for February being tripled in several areas), meant that the groundwater level by the end of winter 2001/02 was equal to the highest level recorded during the preceding 20-year period. Also, the very precipitation-poor winters of 1995/96 and 1996/97 meant that the groundwater table in these years decreased to a level corresponding to the lowest measured during the preceding 20-year period.

6.2 Nitrate in groundwater

As shown in figure 6.3 the highest number of intakes with nitrate >25 mg/l (the former limit level for drinking water) was found in agricultural monitoring catchments with the youngest groundwater – i.e. approx. 53%. As to line and point monitored intakes in the groundwater monitoring areas, the corresponding figure is approx. 27%, and as low as 5.4% for the waterworks wells. This distribution has remained relatively unchanged since the initiation of the Action Plan on the Aquatic Environment in 1987.

Nitrate content depends on depth

Most analyses of nitrate are of intakes 30-40 metres below soil surface. Not unexpectedly, the highest concentrations of nitrate were found in the upper 10 metres of the soil column, where >50 mg/l nitrate was found in more than 15% of the intakes (figure 6.4).

The reason for this subsurface distribution of nitrate is not only the fact that old groundwater at high depth had a lower nitrate content when formed several decades ago, but also the circumstance that a reduction of the nitrate content (denitrification) occurs when nitrate-containing groundwater reaches the reducing soil. The substances capable of reducing nitrate concentrations are, for instance, organic matter, iron compounds (pyrite), methane and hydrocarbons.

AQUATIC ENVIRONMENT 2003 – Figure 6.3

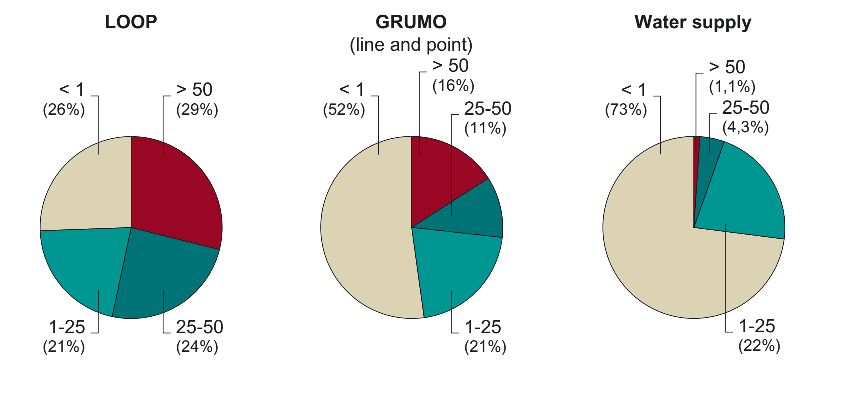


Figure 6.3 Median values for the nitrate content of groundwater (mg NO_3/l) in 2002 for the three monitoring types: LOOP, GRUMO and waterworks' abstraction wells. *GEUS, 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 6.4

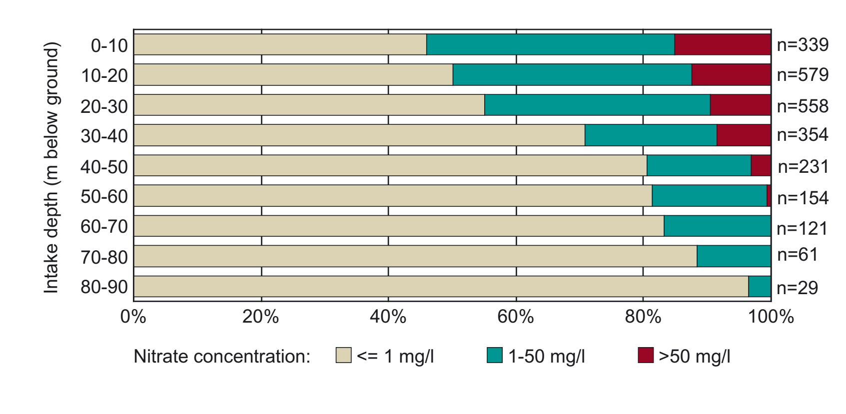


Figure 6.4 Intakes divided according to nitrate concentrations (mg/l) and intake depth below terrain for LOOP, GRUMO, waterworks' abstraction wells and "other wells". Only 2002 data are included. *GEUS, 2003.*

6.3 Status of nitrate in the groundwater monitoring areas

The oxic upper groundwater

To illustrate the development over time of nitrate concentrations in the upper, often nitrate contaminated, groundwater, figure 6.5 depicts median values for the nitrate levels of the oxic upper groundwater.

Nitrate concentrations in the oxic groundwater exhibit significant interannual variations, but the median value (50% above and 50% below) for the 1990-2002 period varies only slightly. From 1990 to 1998, an insignificant increase appeared, from approx. 34 mg/l to 50 mg/l nitrate, after which a decline to approx. 35 mg/l in 2002 occurred.

Most of the groundwater in the groundwater monitoring areas was formed before 1990, and an effect of the measures adopted under the Action Plans on the Aquatic Environment is therefore not expected to be reflected in the average concentrations of nitrate. The oxic groundwater is the youngest, although it consists of groundwater of different ages.

However, analyses of the individual intakes of young groundwater (6-8 years old) in the groundwater monitoring areas reveal declining concentrations of nitrate during the past 13 years in approx. one third (= 39) of the intakes.

Agricultural monitoring areas: subsurface groundwater
The groundwater of the agricultural monitoring areas is the youngest water monitored. The nitrate concentrations of this groundwater, divided into sandy and clayey soils, are shown in the box diagram of figure 6.6 together with winter precipitation values. Only nitrate data from groundwater samples taken in quarters 4 and 1 are included.

The diagram reveals a connection between winter precipitation levels and the level of nitrate in sandy areas lasting until the winter of 97/98 when the nitrate level in sandy soils decreased. Each year following harvest and possible withering of crops, a nitrate pool builds up in the soil due to mineralization of plant remains, and if precipitation levels in autumn and winter are high a large pool of nitrate will be added to the young groundwater. Thus, the groundwater of agricultural monitoring catchments appears to be impacted by winter precipitation and a trend towards declining nitrate concentrations in the upper groundwater can be detected for sandy soils. For clayey soils, a similar trend cannot be observed.

Nitrate in groundwater – status and trends
A general conclusion as to nitrate concentrations in the upper groundwater is that a trend towards declining concentrations exists, reflecting the measured and calculated reduced runoff from cultivated areas.

AQUATIC ENVIRONMENT 2003 – Figure 6.5

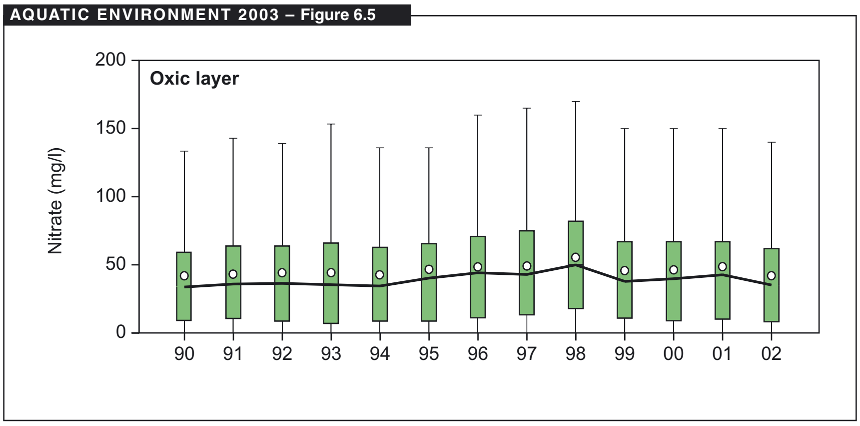


Figure 6.5 Development in nitrate concentrations (mg NO_3/l) during the period 1990-2002 for water samples taken at the upper, oxidised level in GRUMO areas. It is here that signs of a reduction in nitrate concentrations due to decreased runoff will first appear. *GEUS, 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 6.6

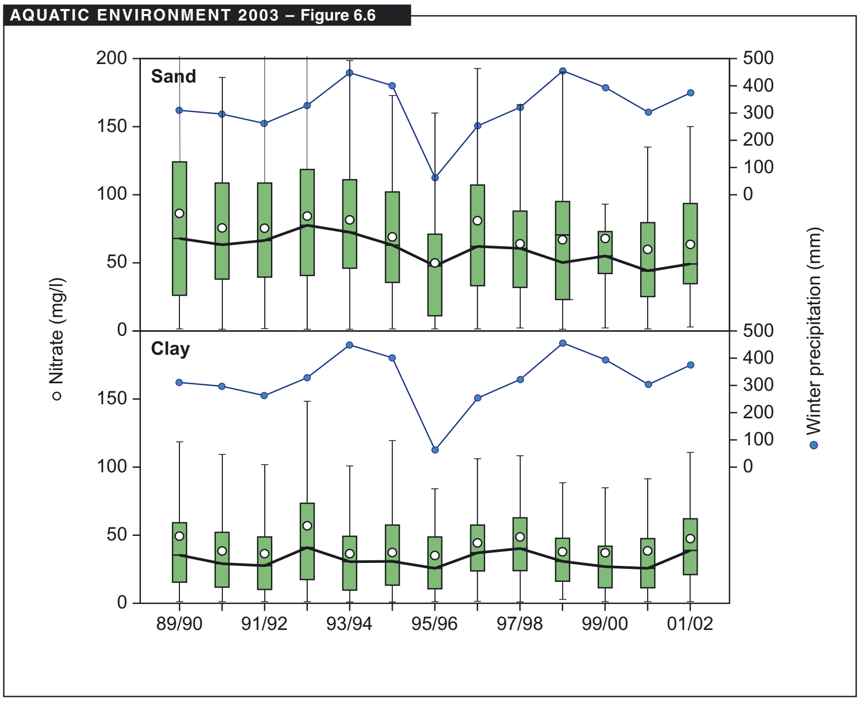


Figure 6.6 Nitrate in the groundwater of LOOP catchments, divided into sandy and clayey areas, compared to winter precipitation (upper curve). Only nitrate data from quarters 4 and 1, nitrate analyses above 1 mg/l and intakes at >5 m depth are included. *GEUS, 2003*.

7 Lakes

The dominant pollution problem in Danish lakes is the increased abundance of lake water algae due in particular to excessive input of phosphorus. Most eutrophic are the sewage polluted lakes, but the improved treatment of wastewater during the past decades means that losses from cultivated areas is now the most significant source of pollution.

The NOVA monitoring programme comprises 27 freshwater lakes and 4 brackish lakes (see map in figure 1.1).

7.1 Nutrient input to the lakes

The amount of sources and the total input of nutrients to each individual lake depend on the lake catchment and its use. A rough characterisation of the catchments of the monitoring lakes is given in table 7.1. Most lakes have cultivated catchments, and only few lakes receive urban wastewater. The wastewater of table 7.1 includes both input from towns and scattered dwellings.

Source apportionment of phosphorus

As in earlier years the 2002 input of phosphorus and nitrogen to the lakes was dominated by input from the open land, constituting approximately 70% of both the phosphorus and nitrogen input. It is difficult to divide the input from open land into natural background loss and losses caused by the cultivation of farmland. For the NOVA stream catchments Bøgestrand (ed.) (2003) has estimated nutrient losses from cultivated areas to be 2.5-4 times higher than the loss from uncultivated areas. This probably applies to the NOVA lake catchments also.

Development in phosphorus input

The average phosphorus load to the monitored lakes has been reduced by almost 50% during 1996-2001 compared to 1989-95. Since the implementation of the monitoring programme in 1989 the phosphorus concentrations of inlet water have declined markedly (figure 7.2). The annual mean of total phosphorus has decreased by almost 50%, from 0.204 mg P/l in 1989 to 0.109 mg P/l in 2002. The most pronounced reduction has occurred in the most nutrient-rich and most sewage polluted lakes. The reduced phosphorus input has also resulted in lower phosphorus concentrations in the lake water. In 16 of the 27 lakes a significant decrease in annual mean lake water phosphorus concentrations has been recorded, whereas an increase has only been observed in 2 lakes. To all lakes unaffected by wastewater discharge the phosphorus input remains unchanged.

Also the input of nitrogen to the lakes has decreased significantly in 15 of the 27 freshwater lakes.

AQUATIC ENVIRONMENT 2003 – Table 7.1

NOVA Lake catchments 2002	Number
Wastewater > 25% of P input	11
> 50% of cultivated areas	19
> 50% paved areas	3
> 50% woods and uncultivated areas	4

Table 7.1 Catchment characteristics of the 31 investigated lakes. *Jensen et al., 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 7.1

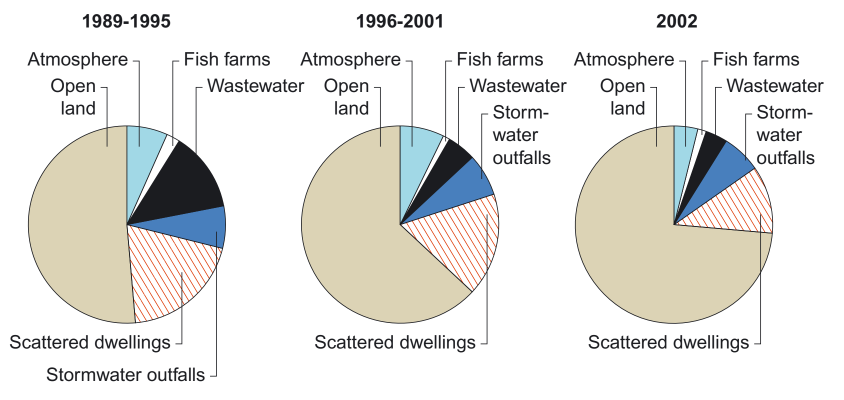


Figure 7.1 Percentage source distribution of the phosphorus input to the monitoring lakes for the periods 1989-95 (left), 1996-2001 (middle) and 2002 (right). The distribution has been calculated as the averages of the percentage distribution for each individual lake. *Jensen et al., 2003*.

7.2 Development of water quality

Generally improved water quality of lakes

From 1989 to 2002 mean Secchi depth has increased from 1.5 to 1.6 m, and chlorophyll has declined from 73 to 55 mg/l during the same period (figure 7.3). In 11 and 13 lakes, respectively, significant improvements have been recorded for chlorophyll levels and Secchi depth. Only in 1 and 3 lakes, respectively, has significant deterioration been recorded.

Phytoplankton biomass has declined significantly in 6 of the 27 lakes, while having increased in 2 lakes. The changes are particularly pronounced within the communities of bluegreen and green algae, but also dinoflagellate and yellow algae communities have undergone changes. Thus, the biomass of bluegreen and green algae has generally declined, whereas the biomass of dinoflagellates and yellow algae has increased during the monitoring period. The relative composition of the phytoplankton has also changed in many lakes. Thus, the percentage of bluegreens has increased in 7 lakes, but declined in 6 lakes. The pure water group of yellow algae has also increased in many lakes – especially in recent years (table 2.6 in *Jensen et al. 2003*).

AQUATIC ENVIRONMENT 2003 – Figure 7.2

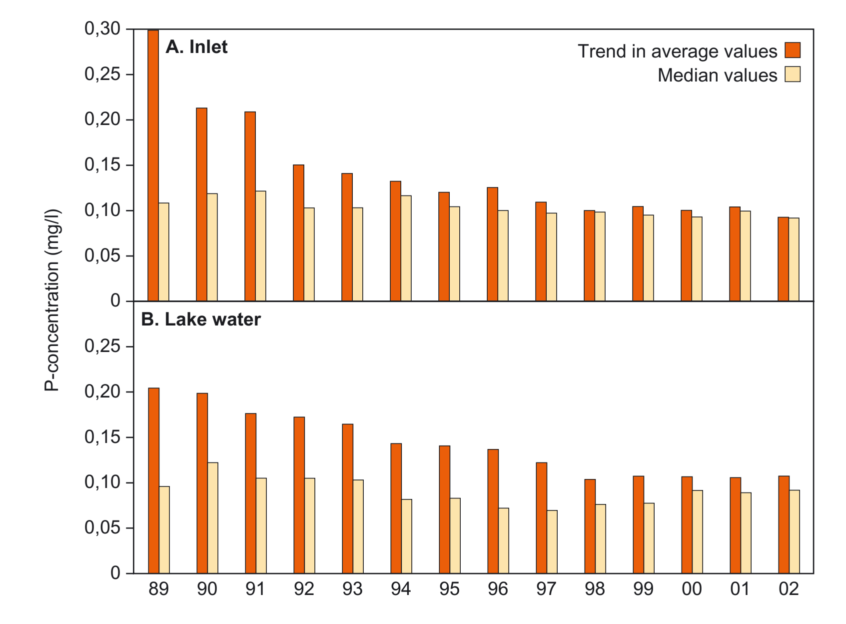


Figure 7.2 Development in mean and median values (annual mean) of phosphorus concentration in inlets and lake water of the 27 freshwater monitoring lakes for the period 1989-2002. *Jensen et al., 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 7.3

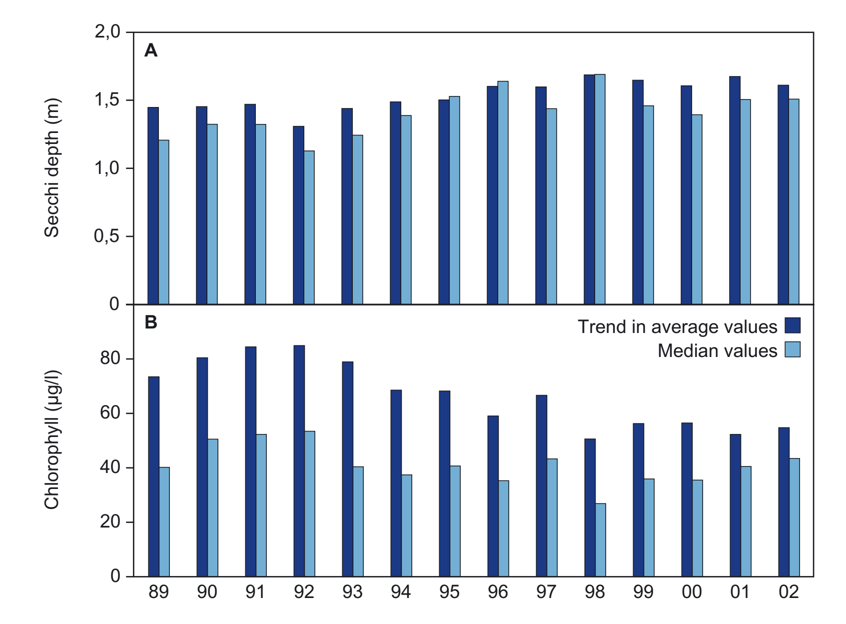


Figure 7.3 Development in mean and median values (summer) for Secchi depth and chlorophyll a concentrations in the 27 freshwater monitoring lakes for the period 1989-2002. *Jensen et al., 2003.*

Nutrient retention in lakes

Nitrogen and phosphorus are retained in lakes. This retention reduces lake water nutrient concentrations as well as the input of nutrients to downstream waterbodies such as lakes and fjords. Phosphorus retention occurs via settlement and accumulation in lake sediments, whereas nitrogen retention is due to the conversion of nitrate into atmospheric nitrogen (denitrification).

In 2002 the phosphorus balance was negative in about one third of the lakes, i.e. the lakes released more phosphorus than they received due to release of phosphorus from lake sediment after the loading reduction (figure 7.4). However, in several lakes this sediment release seems to be decreasing, and in the next couple of decades phosphorus retention is expected to increase in the formerly wastewater polluted lakes.

There is nearly always a net retention of nitrogen in lakes, and the present percentage of retention (figure 7.5) is expected to remain almost unchanged in the future. This retention occurs particularly as a consequence of conversion of nitrate into atmospheric nitrogen, reducing the nitrogen concentrations in the lake as well as in downstream water bodies.

Environmental state in lakes

The environmental state of the monitoring lakes as a whole has improved from 1989 to 2002, especially owing to the reduction in phosphorus inputs (*Jensen et al., 2002).*

Improvements in the environmental state have especially been registered for the physico-chemical parameters (i.a. phosphorus concentrations and Secchi depth) and biological structure (particularly phytoplankton). The reduction in the phosphorus input to the lakes owes especially to the quality objectives employed before 1989 by the counties for improved wastewater treatment and the wastewater treatment requirements in the Action Plan on the Aquatic Environment. Only the diffuse phosphorus input, including agricultural input from the open land, has not decreased during the monitoring period. This and input from scattered dwellings are thus the only pollution sources of significance still to be adjusted to further improve the environmental state. As the situation is today, the improvements obtained so far have not been sufficient for lakes to meet their quality objectives.

The quality objectives for lakes with primarily cultivated catchments will only be met if the phosphorus input from cultivated areas is reduced. This is the case for most Danish lakes.

AQUATIC ENVIRONMENT 2003 – Figure 7.4

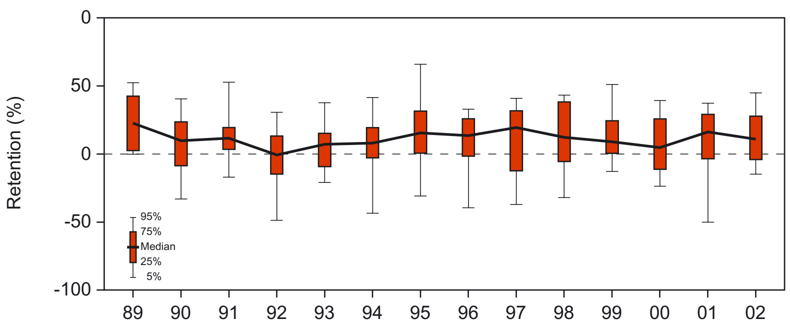


Figure 7.4 Total phosphorus retention (%) for 16 lakes during the period 1989- 2002. Range of variation is shown for each individual year. *Jensen et al., 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 7.5

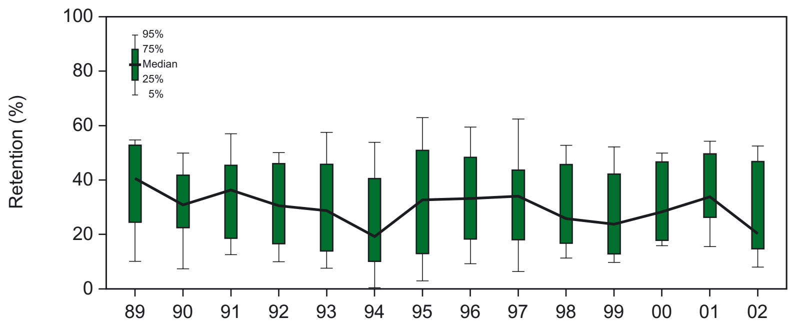


Figure 7.5 Total nitrogen retention (%) for 16 lakes during the period 1989- 2002. Range of variation is shown for each individual year. *Jensen et al., 2003*.

8 Streams

Most Danish streams are affected environmentally by the physical changes imposed to streams over the years in form of channelisation and the construction of weirs and dams, and the stream maintenance still taking place to enable agricultural cultivation of adjacent land. The other major source of pollution, organic matter from wastewater discharges, has been widely remedied by the wastewater treatment of the recent decades. Nutrient concentrations are of no great significance for the environmental state of Danish streams.

NOVA, the Danish Aquatic Monitoring and Assessment Programme, comprises 231 water chemistry monitoring stations (figure 1.1) and approx. 1,000 biological stations. The water chemistry results are used for detecting possible relationships between the stream catchment and the water quality of the stream, and for calculating the transport of nutrients to lakes and marine waters (*Bøgestrand (ed.), 2003*).

8.1 Transport af nutrients via streams

The total river discharge to the Danish marine waters in 2002 is calculated at approx. 18,434 million m^3 , corresponding to a total runoff of 429 mm from Denmark as a whole. It is considerably above the normal, and the discharge was particularly high during the first three months of the year. Also the summer months July and August had far higher river water discharge than the normal (see figure 1.2)

AQUATIC ENVIRONMENT 2003 – Table 8.1

	Organic matter (BOD_5) (tonnes)	Nitrogen (tonnes)	Phosphorus (tonnes)
Background loss	11,100	12,700	440
Agricultural load	7,300	74,900	1,160
Scattered dwellings	3,800	1,000	220
Point sources to freshwater	6,500	4,200	480
Retention in freshwater	-	-4,300	-10
Runoff to the sea via streams	**28,700**	**88,500**	**2,290**
Direct wastewater discharges to the sea	8,100	3,300	430
Marine fish farms	1,700	300	30
Total input to the sea	**38,500**	**92,100**	**2,750**

Table 8.1 Input of BOD_5, nitrogen and phosphorus via streams and direct discharges to marine waters in 2002. *Bøgestrand (ed.), 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 8.1

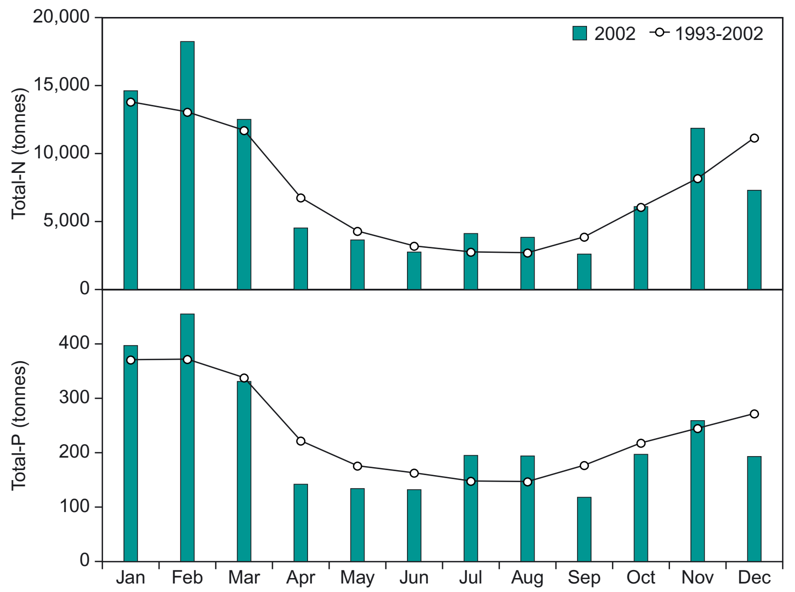


Figure 8.1 Monthly input of nitrogen (N) and phosphorus (P) via streams and direct wastewater discharges to marine waters in 2002 compared with mean values for the period 1993-2002. *Bøgestrand (ed.), 2003*.

Variation in nutrient transport

The annual variation in nutrient transport from the land to marine waters (figure 8.1) reflects the variation in water runoff. In spite of the general reduction in nutrient inputs from land, several months of 2002 exhibited runoff above the average for the period 1993-2002. This has resulted in an increase in available nutrients in the coastal waters. Concomitantly, the direct input of nitrogen from the atmosphere to marine waters has probably been high.

Nutrient inputs to marine waters in 2002

In 2002, a total of 92,100 tonnes nitrogen and 2,750 tonnes phosphorus was transported to marine waters (table 8.1). Freshwater transport of nitrogen from Denmark as a whole to the sea was approx. 21 kg/ha.

AQUATIC ENVIRONMENT 2003 – Figure 8.2

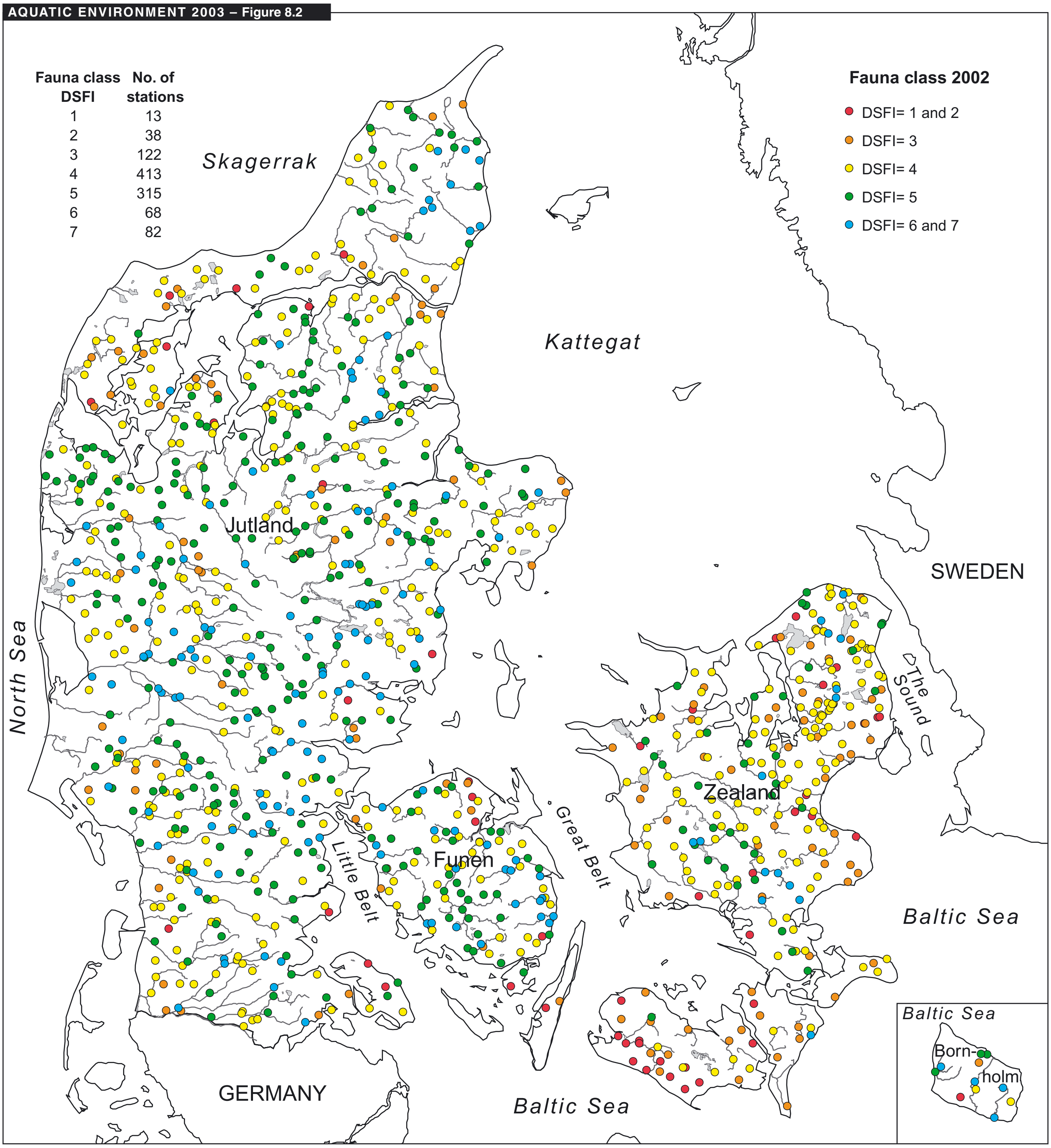


Figure 8.2 Environmental state in Danish streams illustrated by means of the macroinvertebrate fauna. Blue circles (DSFI 6 and 7) illustrate "only slightly affected" streams, while red and orange circles (DSFI 1-3) illustrate a very bad state of the stream water quality. *Bøgestrand (ed.), 2003.*

8.2 Biological quality of streams

The biological quality of streams is assessed annually on the basis of the composition of the macroinvertebrate fauna in more than 1,000 localities. The state is described by means of the Danish Stream Fauna Index (DSFI) with values (fauna classes) from 1 to 7 where the value 7 is given for the highest biodiversity.

Fauna classes 5, 6 and 7 characterising comparatively clean and physically varied streams were found in just over 44% of the streams in 2002 (figure 8.2). Another 39% of the streams had a moderately affected macroinvertebrate fauna (fauna class 4). Fauna classes 1, 2 and 3 characterising a bad or poor state were found in less than 17% of the streams.

The environmental quality was generally better in large streams than in small streams. Hence the proportion of streams with fauna classes 6 and 7 increased with increasing width from 10% (0-2 m) to 36% (>10 m). At the same time, only very few of the large streams have fauna classes 1, 2 and 3.

8.3 Trend in biological stream quality

Since 1999 the same station network with more than 1,000 localities has been monitored. During the period 1999-2002 there has been a marked improvement with an increasing number of streams in fauna classes 5, 6 and 7 (unaffected or only slightly affected) (figure 8.3). The share of streams in these fauna classes has increased from almost 35% to just over 44%.

The improvement in the biological stream water quality during the period 1999-2002 has resulted in a nationwide increase in quality objective compliance from 39% to 50%. The improvements were achieved gradually throughout the whole period.

Quality objective compliance in the small streams has increased from 37% to 48%. Quality objective compliance in the large streams has increased from 46% to 58%.

Improvements in the biological quality of the small streams are attributable to a combination of improved water quality and improved physical conditions. The biological quality in large streams was improving until 1990, whereas mainly the physical conditions have improved in recent years.

The macroinvertebrate fauna changes gradually with improved living conditions in the stream, but it is a slow process and it may take a long time before the fauna will disperse and colonize previously polluted stream reaches. The impact of some of the improvements in water quality and physical conditions may consequently appear with a delay of several years.

Impact of weed cutting on plants and animals in streams

An analysis of the impacts of weed cutting on plants, macroinvertebrates and fish reveals that streams exposed to weed cutting have fewer plant species (table 8.2). This is because the few plant species that are tolerant towards weed cutting outcompete other species. Weed cutting also affects macroinvertebrates and fish in the streams. The number of individuals of mayflies, stoneflies and caddisflies, which are characteristic of a clean stream, and the freshwater shrimp are reduced by more than 50% after weed cutting, both in relation to the number of species and the number of individuals. The trout density is also reduced in streams exposed to weed cutting.

AQUATIC ENVIRONMENT 2003 – Figure 8.3

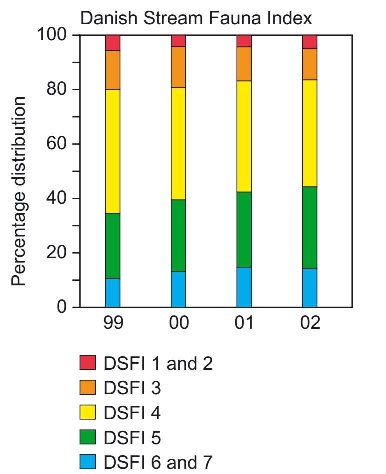


Figure 8.3 Environmental state of Danish streams during the period 1999-2002. Blue and green indicate clean and relatively clean and physically varied streams usally meeting the environmental objective (fauna classes 5, 6 and 7). *Bøgestrand (ed.), 2003.*

AQUATIC ENVIRONMENT 2003 – Table 8.2

Parameter	With no weed cutting	With weed cutting
Plant coverage %	72%	68%
Number of plant species	17.3	10.9
Number of freshwater shrimps	790	420
Number of stoneflies, mayflies and caddisflies	434	108
Number of species of stoneflies, mayflies and caddisflies	7.7	3.6
Number of trout/m^2	108	22

Table 8.2 Characteristic differences between streams with weed cutting and streams with no weed cutting. *Bøgestrand (ed.), 2003.*

AQUATIC ENVIRONMENT 2003 – Table 8.3

Region	Compliance	Non-compliance	Percentage compliance
Jutland	365	299	55%
Funen	58	46	56%
Zealand, Falster, Møn	93	179	34%
Bornholm	7	4	64%
Denmark as a whole	**523**	**528**	**50%**

Table 8.3 Quality objective compliance for streams in the national monitoring network. *Bøgestrand (ed.), 2003.*

Regional differences in stream water quality

Seen from a regional point of view the state of the streams is better in Jutland, and on the islands Funen and Bornholm (figure 8.2). Consequently, 55% of the streams in these areas comply with the stipulated quality objectives (table 8.3). In contrast, only about a third of the stream quality objectives are met on the islands east of the Great Belt.

The regional variations in the state of the streams are attributable partly to the natural differences with low water flow and small slopes in the streams on the islands, partly to a higher human population density and consequently higher wastewater discharges and water abstraction on the islands.

In order to improve the quality of the streams it is necessary first of all to change the physical conditions in the streams so that they resemble the natural conditions with varied stream bed conditions. Many small streams also remain polluted from insufficiently treated wastewater, mainly from scattered dwellings.

AQUATIC ENVIRONMENT 2003 – Table 8.4

Catchment type	N concentration (mg N/l)	N-area-koefficient (kg N/ha per year)	P-concentration (mg P/l)	P-area-koefficient (kg P/ha per year)
Uncultivated	1.52	3.40	0.05	0.11
Agriculture and point sources	5.26	21.2	0.16	0.60
Agriculture with no point sources	6.12	21.4	0.13	0.45

Table 8.4 Average flow-weighted mean concentrations and area coefficient of N and P in stream types in 2002. *Bøgestrand (ed.), 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 8.4

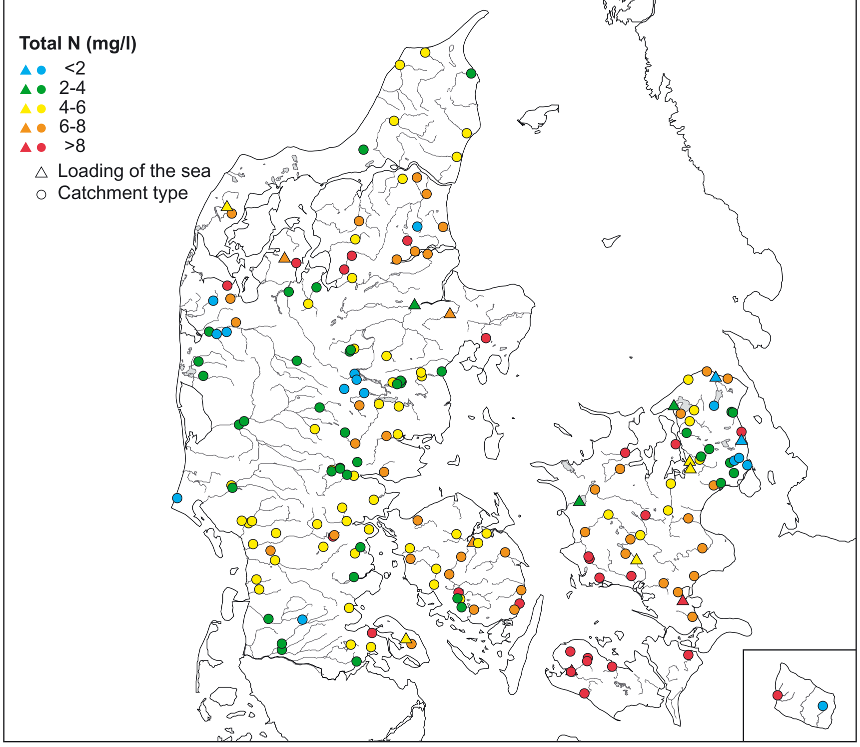


Figure 8.4 Concentration of total nitrogen in streams in 2002. *Bøgestrand (ed.), 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 8.5

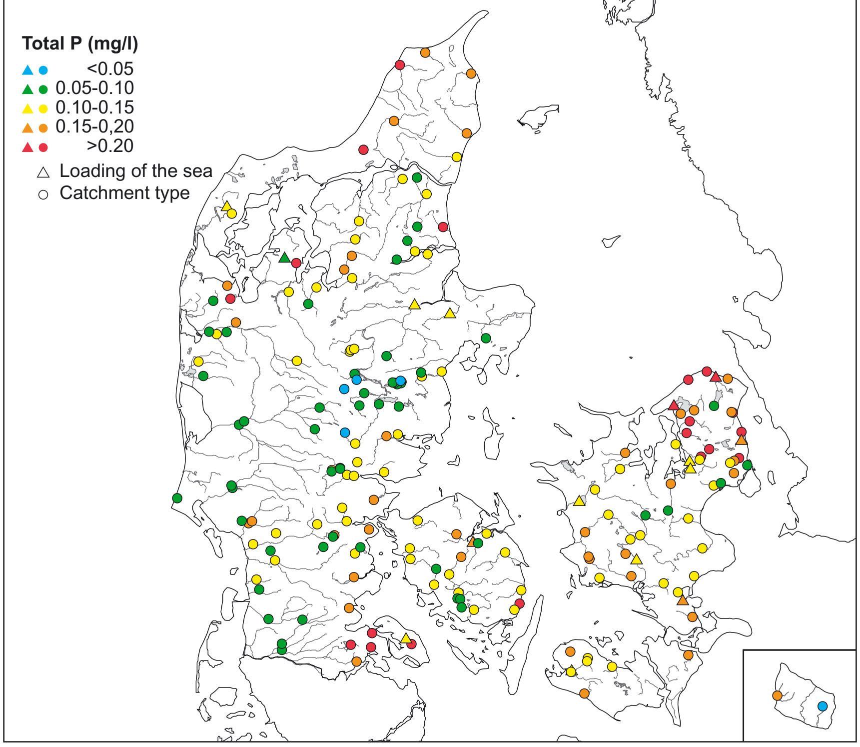


Figure 8.5 Concentration of total phosphorus in streams in 2002. *Bøgestrand (ed.), 2003*.

8.4 Nitrogen and phosphorus in streams

Nitrogen and phosphorus concentrations in Danish streams have no decisive impact on the biological communities in the streams, but are of great significance for the conditions in the lakes and coastal waters that receive the water from the streams. Stream monitoring is used for quantifying nitrogen and phosphorus sources, for calculating inputs to lakes and coastal waters and for describing the trend in nutrient concentrations and transport.

Nitrogen and phosphorus levels in 2002
The flow-weighted annual average concentrations of total nitrogen (N) and total phosphorus (P) are illustrated in figures 8.4 and 8.5 for each monitoring station. P-concentrations are high in streams with a high proportion of wastewater and N-concentrations are high in cultivated catchments. Denitrification of nitrate in groundwater and lakes can, however, result in reduced nitrate concentrations in streams, eg. in the Gudenå river system and in western Jutland.

Nitrogen and phosphorus levels in different catchment types
The characteristic, average variations in concentration levels among streams in the three catchment types indicated in table 8.4 resemble those found in the preceding years. The flow-weighted N and P concentrations in streams in agricultural catchments are approx. 3-4 times higher than the concentrations in uncultivated rural catchments. The differences in N and P losses between uncultivated catchments and agricultural catchments are more pronounced if estimated on basis of the area coefficient, ie. the input per hectare catchment. In that case, the difference is a factor of approx. 4-7. This owes to the water flow being relatively low in streams in uncultivated catchments compared to streams in agricultural catchments.

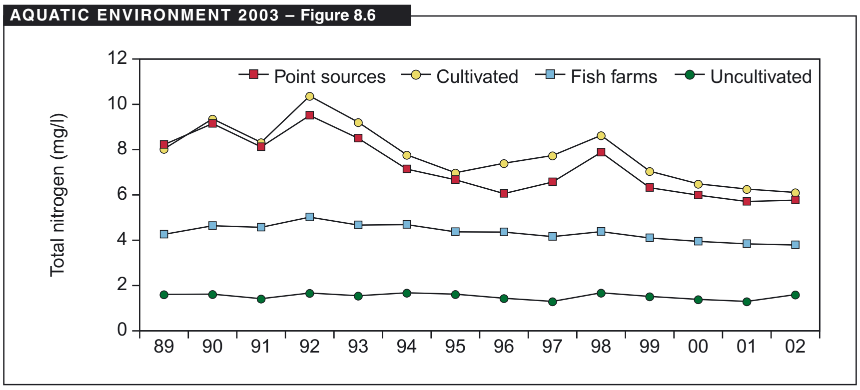


Figure 8.6 Trend in nitrogen concentrations since 1989. Average of flow-weighted annual mean values for streams subjected to different pressures. *Bøgestrand (ed.), 2003.*

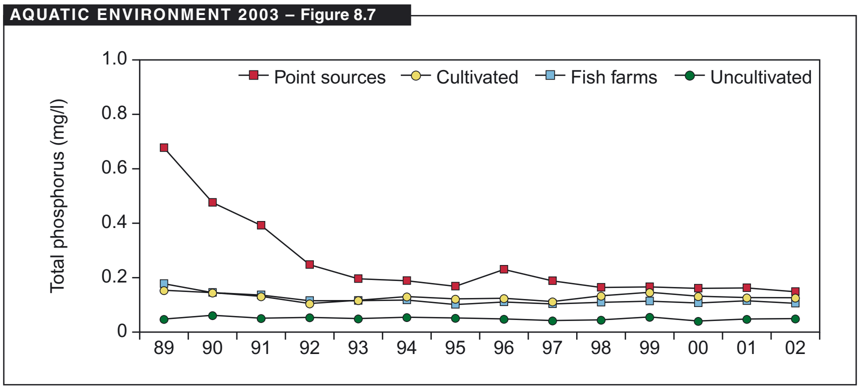


Figure 8.7 Trend in phosphorus concentrations since 1989. Average of flow-weighted annual mean values for streams subjected to different pressures. *Bøgestrand (ed.), 2003.*

8.5 Trends in nutrient concentrations in streams

Nitrogen
Nitrogen concentrations in the streams are generally on the decrease, although concentrations remain almost unchanged in streams in uncultivated catchments. The decrease was most distinct in streams situated in cultivated catchments or in streams with wastewater discharges (figure 8.6). The flow-corrected figures for nitrogen concentration and transport in streams in cultivated catchments and in catchments with wastewater input exhibit a decline of approx. 30% during the period 1989-2002, corresponding to a reduction in nitrogen concentrations in these streams of just over 2 mg/l.

Phosphorus
Average concentrations and transport of total phosphorus in streams affected by wastewater have declined by approx. 40% since 1989 (figure 8.7). The decrease is due to improved phosphorus removal from wastewater, especially during the 1990s. The phosphorus level increased during the dry year 1996, but has been stable since 1998. Phosphorus concentrations in streams in cultivated catchments with no wastewater input have not changed significantly during the period 1989-2002.

8.6 Trends in nutrient transport with freshwater to coastal waters

Wastewater treatment

Enhanced wastewater treatment is of considerable importance for the input of nutrients to marine waters. Total wastewater discharges fell from approx. 9,000 tonnes phosphorus per year during the period 1981-88 to approx. 1,000 tonnes in 2002, corresponding to a reduction of approx. 90%. Wastewater discharges of nitrogen declined from approx. 28,000 tonnes per year from 1981-1988 to approx. 8,000 tonnes per year in 2002, corresponding to a reduction of approx. 70%. In recent years (from about 1996) there has only been a slight decline in wastewater discharges of nitrogen and phosphorus to freshwater, and the significant reduction that took place in the early 1990s has now stagnated (figure 8.8).

Total nutrient input from land to the sea

Since the implementation of the first Action Plan on the Aquatic Environment the total discharges of both nitrogen and phosphorus to coastal waters have fallen significantly. Improved wastewater treatment is accountable for the phosphorus decrease while the decrease in nitrogen is attributable to a considerable reduction in both leaching from cultivated areas and in wastewater discharges.

With correction for variations in runoff, the reduction in the marine nitrogen load is calculated at approx. 40% (with 95% probability between 10% and 57%). The corresponding phosphorus reduction during the same period is approx. 75%.

The total nitrogen input in tonnes/year from land to marine waters (figure 8.8) has not declined during the period 1989-2002. In contrast, the absolute phosphorus input has fallen by approx. 60%. The total nitrogen input has not declined because the level of precipitation has been above average during the recent 5 years.

In addition to the nutrient inputs illustrated in figure 8.8, Danish marine waters have received inputs from our neighbouring countries and with the sea currents from adjoining marine waters. These inputs are described in *Ærtebjerg (ed.), 2002*.

AQUATIC ENVIRONMENT 2003 – Figure 8.8

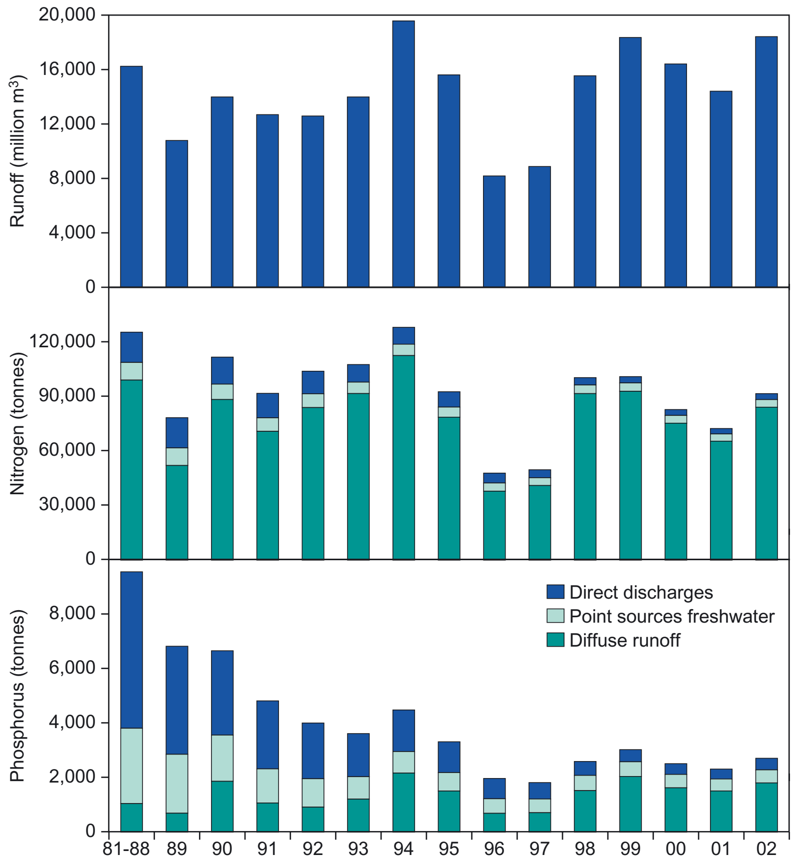


Figure 8.8 Annual freshwater runoff and input of nitrogen and phosphorus via streams and direct wastewater discharges to marine waters for the period 1989-2002 and an average for the period 1981-88. *Bøgestrand (ed.), 2003.*

9 Marine waters

The most significant general pollutants of Danish marine waters are the high inputs of nitrogen and phosphorus from land and from the atmosphere. Shallow Danish marine areas are more vulnerable to eutrophication than most other marine areas as the water exchange with the open sea is often negligible, and because stratification often limits the input of oxygen to the bottom water.

The NOVA monitoring programme on marine waters comprises hydrographic, chemical and biological measurements divided into 3 main groups of investigation:

- Monitoring of the water column (figure 1.1)
- Bottom flora and invertebrates
- Heavy metals and environmentally hazardous substances.

The measurements are undertaken mainly in coastal and inner waters (the Kattegat and the Belt Sea), but several monitoring stations for measurement of water chemical parameters are also located in the North Sea (*Rasmussen et al., 2003*).

AQUATIC ENVIRONMENT 2003 – Table 9.1

N and P input to Danish lakes 2002	Nitrogen (tonnes/ year)	Phos-phorus (tonnes/ year)
Freshwater runoff	88,500	2,290
Direct point sources to the marine waters	3,600	460
Atmospheric deposition	107,000	approx. 400
Total input	**199,100**	**3,150**

Table 9.1 Input of nitrogen and phosphorus to the Danish lakes from land and via the atmosphere in 2002. *Bøgestrand (ed.), 2003* and *Ellermann et al., 2003.*

9.1 Status and trends – oxygen deficiency

The level of nutrient inputs generally determines the degree of eutrophication of marine areas, but the state of a particular year depends strongly also on weather and wind conditions. Of particular importance in 2002 was the high amount of precipitation, especially during the winter months and in July-August, as well the warm summer and low wind speed during the last six months of 2002 (*Rasmussen et al., 2003*). These factors led to the most severe oxygen deficiency ever recorded in Danish marine waters.

Nutrient concentrations

In 2002 the freshwater runoff was 18,400 mill. m^3 (429 mm), which is approx. 30% above the normal for 1971-2000. The nutrient runoff to coastal areas via watercourses and direct sewage discharges, including marine fish farms, was 92,100 tonnes nitrogen and 2,750 tonnes phosphorus in 2002. The seasonal variations in runoff deviated from the norm by exhibiting extraordinarily high levels in February, July, August and November (figure 1.2).

Oxygen deficiency in 2002

In late July and the beginning of August, the bottom water oxygen concentrations of the inner Danish marine

AQUATIC ENVIRONMENT 2003 – Figure 9.1

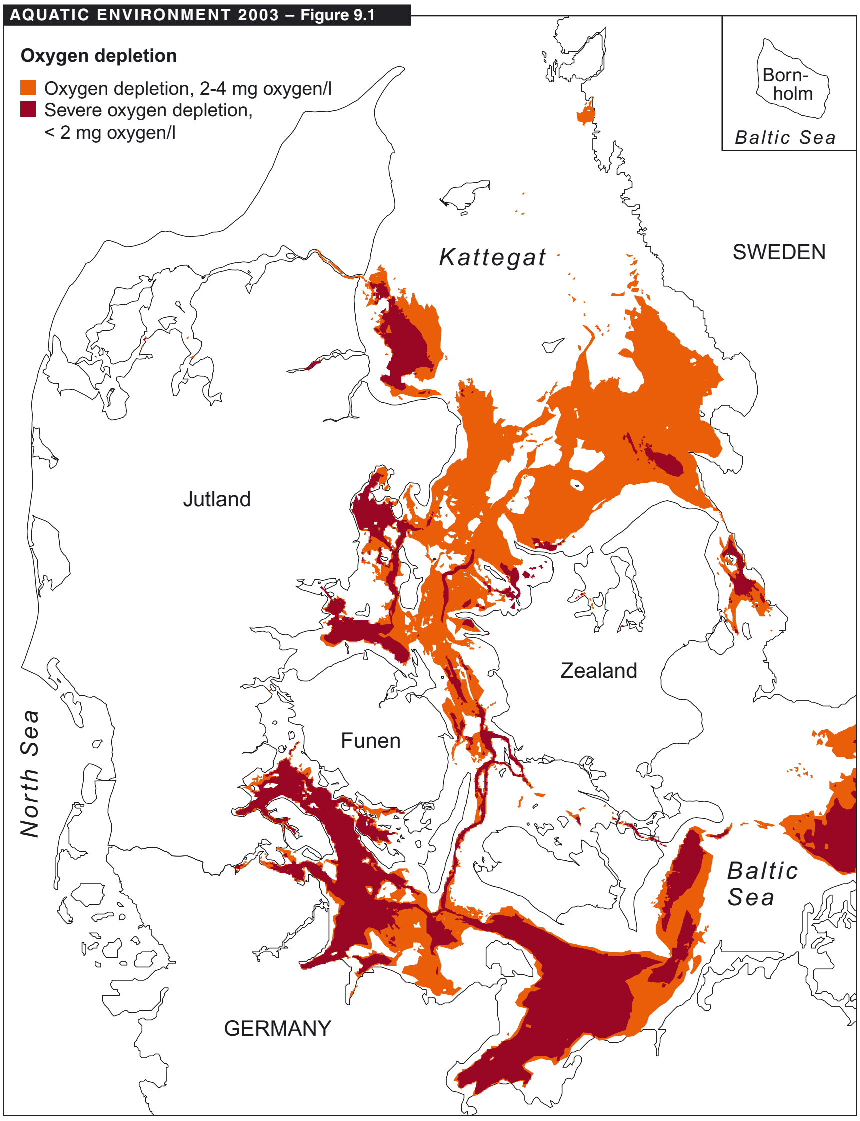


Figure 9.1 Occurrence of oxygen depletion and heavy oxygen depletion during the period 30 September-4 October 2002. *Rasmussen et al., 2003.*

waters declined to exceptionally low levels, and widespread oxygen deficiency developed in the Belt Sea, the Sound, the Kattegat and the Arkona Sea. The oxygen deficiency peaked at the end of September and the beginning of October when approx. 15,000 km² of inner marine waters and adjacent fjords were affected by oxygen deficiency (<4 mg O_2/l) (figure 9.1), 5,500 km² being severely affected (<2 mg O_2/l). In the southern part of the Little Belt, Flensburg Fjord, the Belt Sea and in waters north of Funen, hydrogen sulphide occurred in the bottom water, an indication of complete absence of oxygen. Hydrogen sulphide is highly toxic to most organisms.

In the beginning of October periods with heavy wind from westerly and northerly directions occurred. This led to inflow of oxygen-depleted bottom water from the Kattegat to the east coast of Jutland, and dead invertebrates and fish were found at the beaches of Aalborg Bay, Vejle Fjord, Kalø Cove, Ebeltoft Cove and the south-east of Djursland. During October the oxygen conditions went back to normal.

AQUATIC ENVIRONMENT 2003 – Figure 9.2

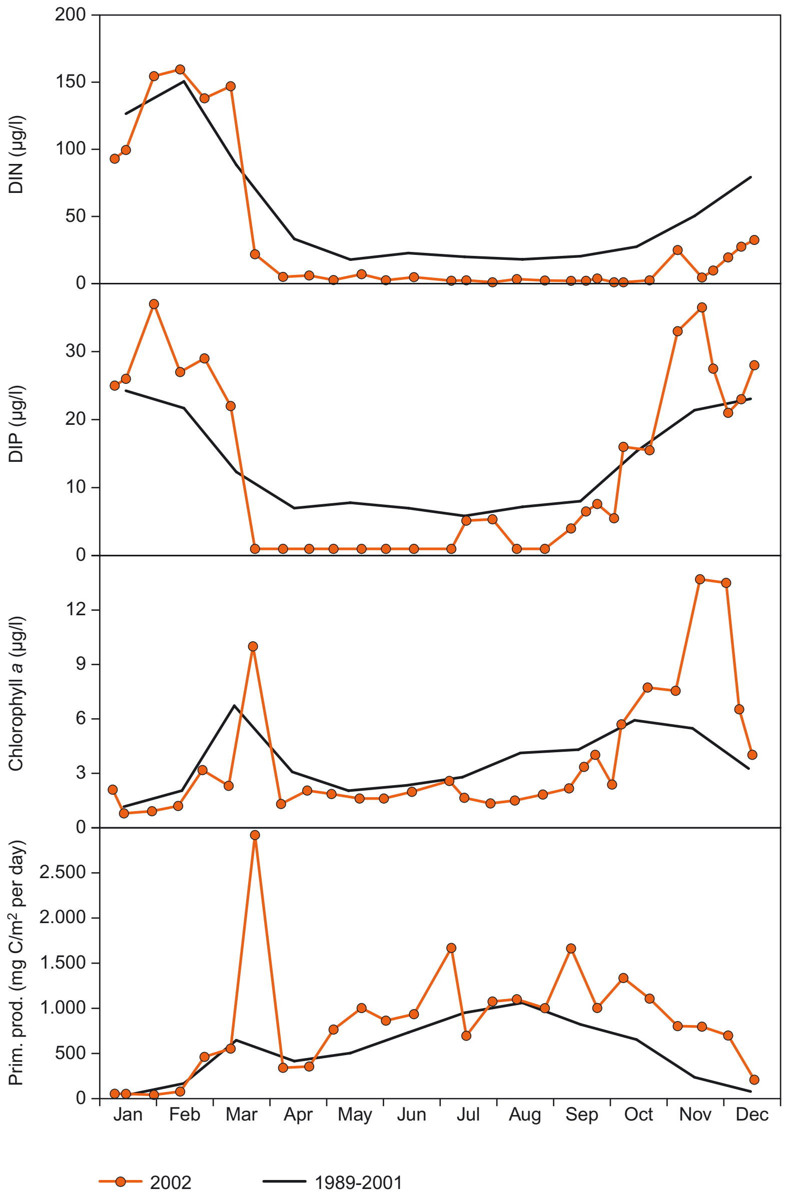


Figure 9.2 Time variations in the concentrations of inorganic N (DIN), inorganic P (DIP), chlorophyll and primary production in the southern Little Belt in 2002 compared to the average for the period 1989-2001. *Rasmussen et al., 2003.*

9.2 Oxygen deficiency in 2002: cause and effect contexts

Natural conditions

Inner Danish marine waters are naturally sensitive to eutrophication, which may easily result in oxygen depletion. The pronounced stratification of the water column triggered by the outflow of brackish Baltic Sea water from the surface and inflow of salt water from the Skagerrak to the bottom prevents export of oxygen from the air and the surface layer to the bottom layer. In summer stratification is further strengthened by the sun's heating of the surface layer. Moreover, the inner marine waters are shallow with a mean depth of approx. 19 m. The transition layer is generally found around 13 m depth. The volume of the bottom water is therefore relatively small (~250 km²) and the quantity of oxygen available for respiration consequently limited.

Open waters of the Little Belt in 2002

The exceptionally high inputs of nutrients from land and the atmosphere during winter 2002 are reflected in the surface water quality. As an example, figure 9.2 depicts the situation in the southern part of the Little Belt during 2002 compared to mean values from 1989-2002.

The winter levels of both N and P were significantly higher in 2002 than in 2001 and higher than or on level with the average for 1989-2002. This led to a severe spring bloom of algae in March-April and thus also to high sedimentation of algae.

The abundance and production of algae stayed at normal levels during summer, and the content of inorganic N and P was generally very low. In connection with the mixing of bottom water in October, high amounts of N and P were exported to the surface water. This stimulated algal production and the highest levels of chlorophyll in the Little Belt were measured in November 2002 (figure 9.2).

In 2002 the consumption of oxygen

in the bottom water was probably higher than usual. The phytoplankton biomass was generally above average and dominated by diatoms that are known to sediment in the event of nutrient limitation. Most likely therefore, the concentrations of sedimented organic matter at the seafloor were higher than normal. To this should be added that bottom temperatures were slightly higher than usual, the largest deviation of approx. 1 °C occurring in August (*Rasmussen et al., 2003*). The unfortunate combination of high nutrient inputs, a warm summer and absence of heavy winds is thus the identified cause of the 2002 oxygen depletion. A quantitative estimation and comparison of the impact of the different parameters cannot be made.

9.3 Overall trends in the environmental state of marine waters

Nutrient concentrations in fjords and coastal waters

Nitrogen and phosphorus concentrations in both fjords and open coastal waters declined during 1989-2002, though not steadily so, as the size of the decline depends on the level of pre-

AQUATIC ENVIRONMENT 2003 – Figure 9.3

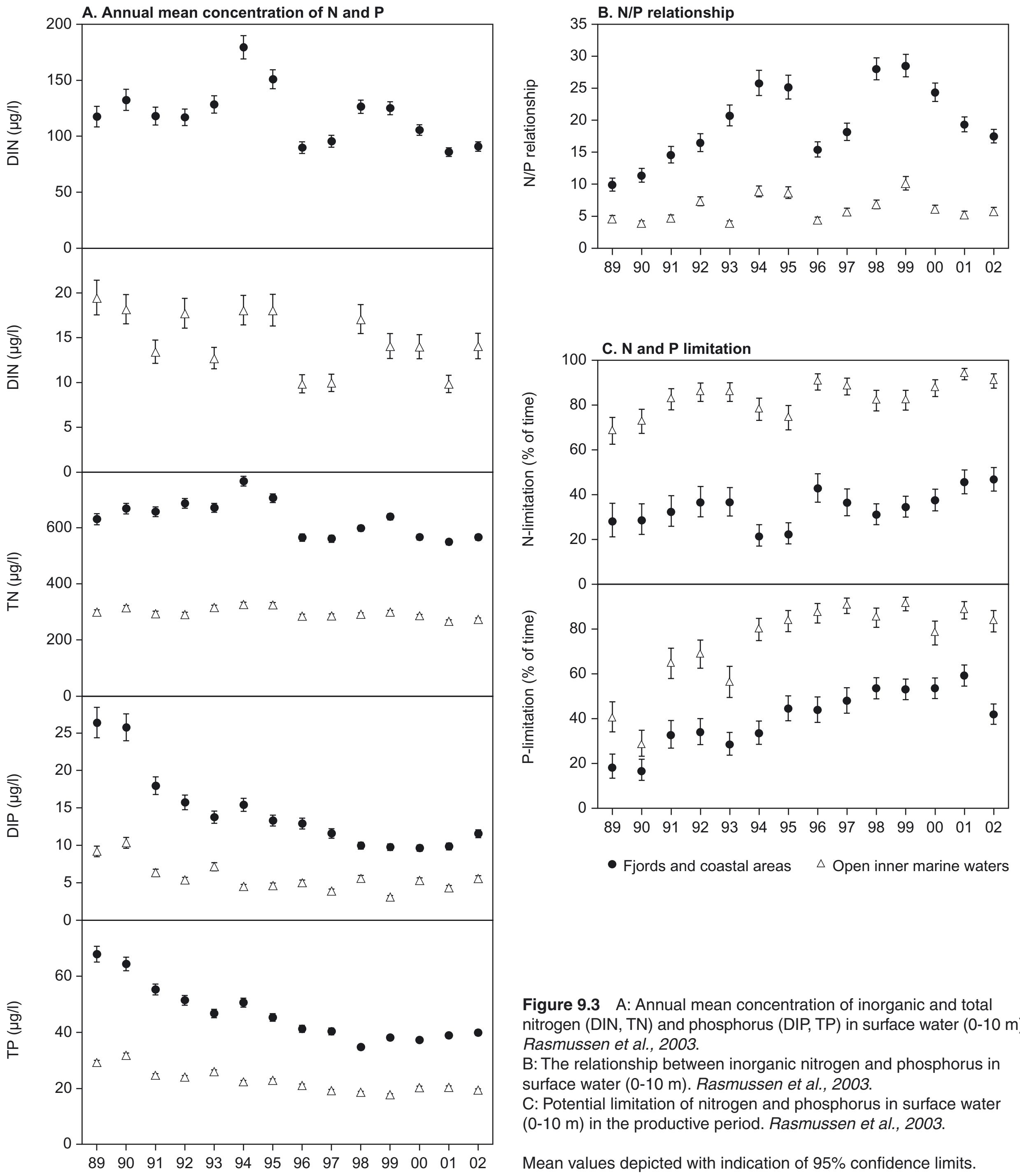


Figure 9.3 A: Annual mean concentration of inorganic and total nitrogen (DIN, TN) and phosphorus (DIP, TP) in surface water (0-10 m). *Rasmussen et al., 2003.*
B: The relationship between inorganic nitrogen and phosphorus in surface water (0-10 m). *Rasmussen et al., 2003.*
C: Potential limitation of nitrogen and phosphorus in surface water (0-10 m) in the productive period. *Rasmussen et al., 2003.*

Mean values depicted with indication of 95% confidence limits.

cipitation and freshwater runoff. This positive development primarily owes to the Action Plan on the Aquatic Environment I as to phosphorus and to the Action Plans on the Aquatic Environment I and II as to nitrogen. Similar initiatives in our neighbouring countries may also have contributed to the lower levels in open Danish marine waters.

The decline in the N and P content is most pronounced in the fjords to which almost the total nutrient input is land-based (figure 9.3A). The decline in phosphorus concentrations seemed highest in the beginning of the 1990s, while the decline in nitrogen levels did not occur until around 2000.

In consequence of the reduction of the land-based phosphorus input, the N:P ratio in fjords and inner marine waters rose during 1990s; however, 1996 and 1997 differ markedly from the remaining years in that the nitrogen input was very low during these two very dry years (figure 9.3B). Around 2000 the N:P ratio decreased, probably mainly due to the reduced nitrogen input from land.

Increased nutrient limitation

The decline in N and P levels has led to increased nutrient limitation of algal growth. The estimated potential extent of last year's reduced algal growth in fjords and inner marine areas due to nitrogen and/or phosphorus limitation is shown in figure 9.3C. The estimations are based on the assumption that potential limitation occurs at concentrations lower than 28 mg l/1 for inorganic N and 6.2 mg l/1 for inorganic P. The increase in potential nutrient limitation is particularly strong in fjords. Algal concentrations are, however, not only determined by a possible nutrient limitation, but also by, for instance, the extent of algal grazing by, most typically, zooplankton or mussels.

9.4 Trends in phytoplankton abundance and oxygen depletion

Phytoplankton abundance

A trend towards reduced phytoplankton abundance (chlorophyll) and production combined with a simultaneous increase in Secchi depth can be detected since the 1980s in fjords and inner marine waters (figure 9.4). When correcting figure 9.4 for annual differences in weather conditions, only negligible changes seem to have occurred in the fjords since 1993, whereas increased Secchi depth and reduced phytoplankton abundance become more evident for the open inner marine waters (*Rasmussen et al., 2003*).

AQUATIC ENVIRONMENT 2003 – Figure 9.4

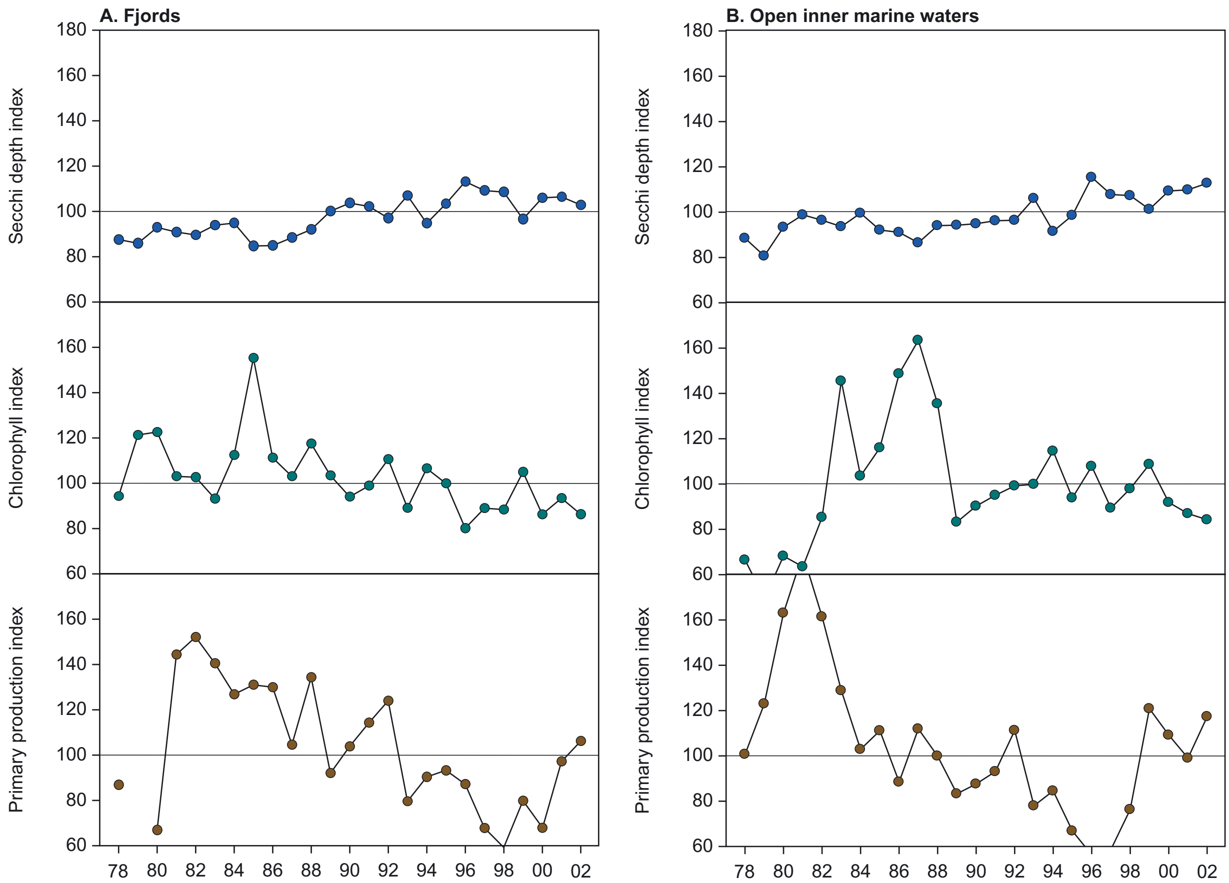


Figure 9.4 Development in the indices for Secchi depth, chlorophyll concentrations and primary production in A: fjords and B: open inner waters. *Rasmussen et al., 2003.*

Relationship between phytoplankton abundance and oxygen depletion

The reduced nutrient concentrations and the increased potential limitation of phytoplankton production were expected to imply a reduced risk of oxygen depletion in marine areas. Measurements of oxygen concentrations since 1989 do not, however, suggest that the frequency of oxygen depletion is on the decline. On the contrary, the results (figure 9.5) show a trend towards declining oxygen concentration in the bottom water of both fjords, coastal monitoring stations and open marine waters until 2002. This evidences that oxygen depletion is not related only to the existing nutrient input, also other factors come into play. Apart from the meteorological conditions it is probable that the chemical and biological responses to changing inputs may be delayed, and that changes in the biological structure of marine ecosystems may be involved. The eutrophication-conditioned influences will eventually, however, be determined by the level of nutrient inputs.

9.5 Benthic flora and fauna

A decline in the input of nutrients will result in improved Secchi depth and better light conditions. The depth distribution and coverage of the benthic flora will thus expand to deeper water. At the same time a nutrient reduction will reduce the abundance of eutrophication-stimulated algae and hence further improve the growing conditions for eelgrass and perennial algae. In the long term a decreased nutrient input will lead to fewer episodes of oxygen depletion and thus improved conditions for benthic invertebrates and submerged macrophytes.

Eelgrass

The depth limit of eelgrass was highest along the open coasts (4.7-6.2 m), slightly lower in the outer fjords (3.3-4.2 m) and lowest in the inner fjords (2.6-3.6 m) during 1989-2002.

As to open coasts there has been no significant development in depth distribution. Distribution has declined in the outer parts of the fjords, albeit it was markedly higher in 2002 than in 2001. Generally, coverage has declined in the inner parts of the fjords as well.

The trend towards improved Secchi depth is generally not yet reflected by higher depth limits nationwide and increased density and coverage of eelgrass. At several individual sites there seems to be no relationship between Secchi depth and depth limit either. In areas with high abundance of loose-growing algae (e.g. Køge Bay) it is probably the algae that prevent the eelgrass from growing as deep as Secchi depth allows, while in other areas (e.g. Århus Bay) it seems as if oxygen depletion has regulated the dept limit for a number of years.

Eutrophication-related algae

In the inner and outer fjords no significant changes have occurred as to the coverage of eutrophication-related algae during 1993/94-2002, coverage in recent years being, however, lower than in the late 1990s. In contrast, in the outer fjords coverage has declined at water depths from 1 to 6 m since 1994 (*Rasmussen et al., 2003*).

Benthic fauna

During 1998-2002 the level of benthic fauna has remained stable both in coastal areas and in the open marine waters. This applies both to the total number of individuals, biomass, total number of species and species composition. The exceptionally severe oxygen depletion in autumn 2002 meant that the benthic fauna almost completely disappeared from large parts of the areas most seriously affected by oxygen depletion (*Hansen et al., 2003*).

At three long-term monitoring stations located in inner Danish marine waters total benthic fauna density has fluctuated during the past 22 years, with high levels occurring in the beginning of the 1980s and mid-1990s followed by a marked decline. The 2002 values stay at a low level. The composition of the benthic fauna changed during the same period. While the abundance of both bristle worms and crustaceans peaked in the 1980s, only bristle worms dominated in the 1990s (figure 12.1 in *Rasmussen et al., 2003*).

AQUATIC ENVIRONMENT 2003 – Figure 9.5

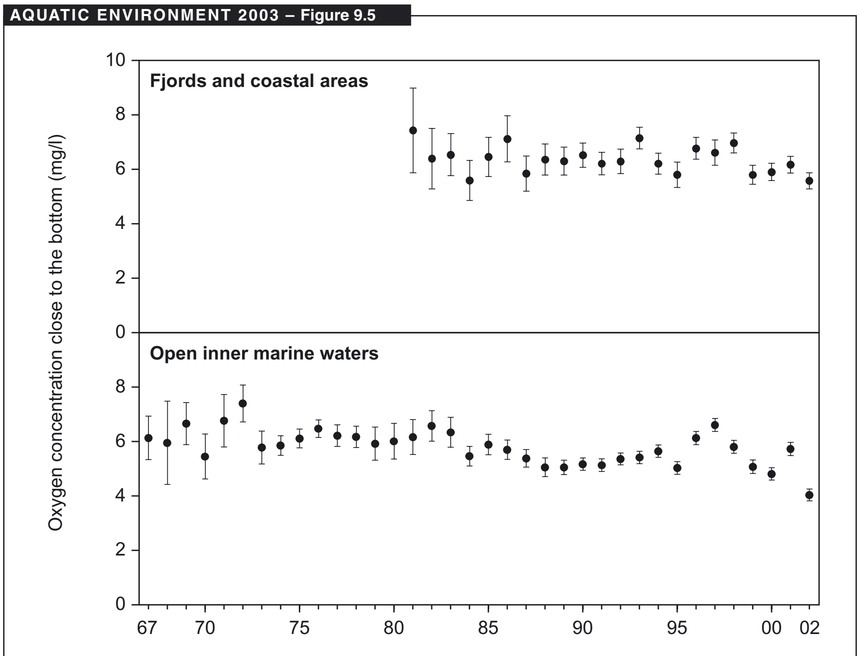


Figure 9.5 Mean oxygen concentrations in the bottom water in NOVA stations in fjords and coastal-near areas and open inner waters. Calculated from above bottom samplings in July-November at clear pycnoclines. *Rasmussen et al., 2003*.

9.6 Structural shift in Ringkøbing Fjord, Western Jutland

History

During the 18th century the salinity of Ringkøbing Fjord (figure 1.1) was probably around 25-30‰, but it declined gradually concurrently with the reduction of the water exchange between the fjord and the North Sea to an opening at Nymindegab. In 1910 a canal was dug at Hvide Sande and this led to an increase in the fjord's salinity (15-25‰) lasting until 1915 when the canal was shut off. Until 1931, when today's sluice was constructed, and until 1995 average salinity has been approx. 6-11‰. Since 1995, consequent to a changed sluice practice, annual salinity is 8-15‰, excepting May-September with 12-15‰. Besides these salinity changes, the most substantive changes are the increased nutrient inputs until ca. 1980 and the reduction in nutrient inputs in recent years owing to improved wastewater treatment.

Changes in water quality and biology

A dramatic improvement of the water quality of Ringkøbing Fjord has been recorded since the increase in salinity as from 1995 (figure 9.6). Algal abundance has declined by more than a factor 5 and Secchi depth has increased from approx. 0.7 to approx. 2 m. The depth limit for submerged macrophytes has also increased, but coverage has drastically declined. This is mainly due to the fact that the change in salinity adversely affected the dominant plant until 1995, the pondweed Potamogeton pectinatus, although it is expected to adapt to the changed conditions with time. The poor coverage of plants is also related to the circumstance that the more salt-tolerant flowering plants, eelgrass and seagrass, have not yet been capable of compensating for the decline in pondweeds. The reduced algal abundance of the fjord has also led to a severe decline in the number of plant-eating birds, particularly Bewick's swan and pintail.

Perspectives

The ecological shift in Ringkøbing Fjord illustrates that changes occurring in a eutrophicated aquatic area do not necessarily relate to changes in the inputs of nutrients, just as they are not easily predictable. The results show that only slightly changed growing conditions may alter the conditions of competition and survival for species that may be of vital importance for the whole ecosystem.

It is uncertain whether the recorded changes can solely be attributed to the changes in sluice practice. Removal of phosphorus from the catchment's wastewater has reduced the phosphorus level of the fjord (see figure 9.6), so that phosphorus has become potentially more limiting for algal growth. The phosphorus level has, however, increased in recent years.

The water quality of Ringkøbing Fjord has significantly improved in consequence of the increased salinity and the reduced phosphorus input. Simultaneously, changes in the fjord have led to a drastic reduction in the number of some bird species. Initiatives to improve the water quality of an area may thus counteract interests of bird protection within the same area.

AQUATIC ENVIRONMENT 2003 – Figure 9.6

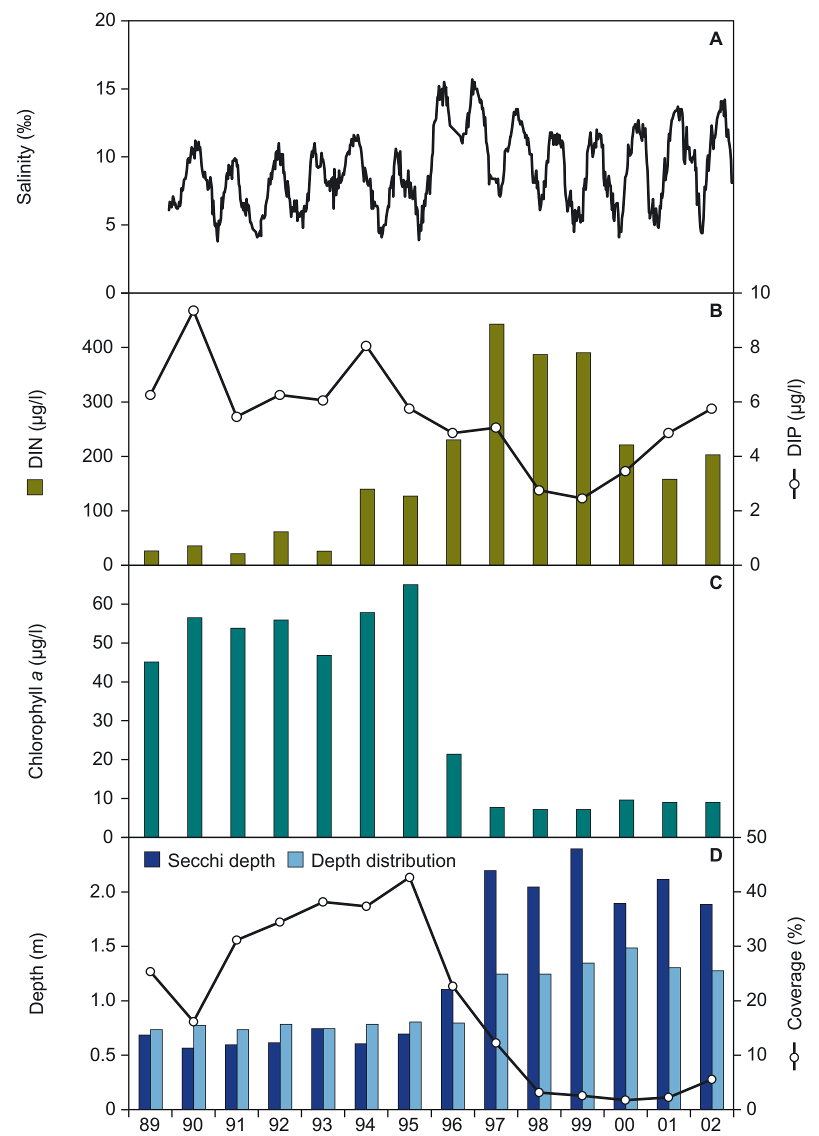


Figure 9.6 Ringkøbing Fjord. Mean values for the period 1989-2002. A: Salinity. B: Summer concentrations of inorganic nitrogen (DIN) and phosphorus (DIP). C: Annual time-weighted concentrations of chlorophyll a. D: Summer Secchi depth, depth limits and coverage of flowering plants. *Rasmussen et al., 2003*.

10 Heavy metals

Heavy metals and other inorganic trace elements occur naturally in the environment in relatively low concentrations. The properties of these substances vary widely; some are injurious to human health even in low concentrations, others are required by the human organism in small doses while being detrimental to the environment in large doses (box 1).

In 2002 monitoring of heavy metals comprised point sources, the atmosphere, groundwater and marine areas. The scope of the meta-analyses varies from subprogramme to subprogramme. A survey of the monitoring programme for heavy metals is found in *Danish EPA, 2000*.

10.1 Sources

Atmospheric deposition

Atmospheric deposition of heavy metals includes both the content in precipitation and the particles that are deposited during dry periods, the so-called dry deposition. Moreover, the concentration of metals bound to airborne particles is measured.

There has been a steady reduction in the deposition and concentrations of heavy metals in the atmosphere for the period 1990 to 2002. The decline in heavy metals has been approx. 50-70%. The contents of lead and cadmium have exhibited the most significant decline (figure 10.1).

The developmental trend follows the changes in the emission concentrations of heavy metals. In Denmark, and in many other northern European countries, significant emission reductions have occurred. However, for some substances only negligible reductions of Danish emissions have occurred, and the observed changes can therefore mainly be ascribed to emission reductions in Northern Europe.

AQUATIC ENVIRONMENT 2003 – Box 1

Character of heavy metals and other inorganic trace elements

1. Toxic substances having detrimental effects on health and the environment (human toxic and ecotoxic), even in low concentrations. These include arsenic, lead, cadmium and mercury. Lead, cadmium and mercury can be accumulated in the food chain.
2. So-called essential substances comprising those necessary to the human organism in small doses, but which are health damaging and ecotoxic in large concentrations. To these belong chromium, copper, nickel, zinc and selenium.
3. A third group of substances that do not normally appear in concentrations so high to constitute a problem, but whose background concentrations may have both human toxicological and ecotoxicological effects when in the right quantity and form.

AQUATIC ENVIRONMENT 2003 – Table 10.1

	Atmospheric deposition (mg/m^2)	Particulate concentrations in the air (ng/m^3)
Chromium	0.12	0.5
Nickel	0.22	1.5
Copper	0.75	1.5
Zinc	7.4	13
Arsenic	0.12	0.6
Cadmium	0.04	0.3
Lead	1.0	5.3

Table 10.1 Average deposition for the Danish background area (far from pollution sources) and average concentrations of particulate metal in 2002. *Ellermann et al., 2003*.

AQUATIC ENVIRONMENT 2003 – Figure 10.1

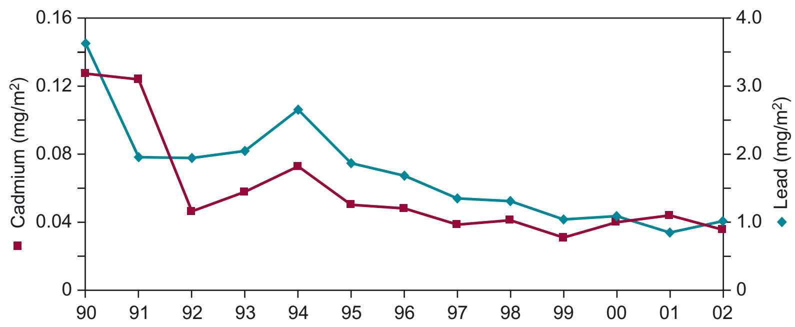


Figure 10.1 Temporal development in wet deposition during a 13-year period of lead (Pb) and cadmium (Cd). Unit: mg/m^2 per year. *Ellermann et al., 2003*.

AQUATIC ENVIRONMENT 2003 – Table 10.2

	Inlet (µg/l)			Outlet (µg/l)			Freshwater quality objectives (µg/l)
	Mean	5%	95%	Mean	5%	95%	
Arsenic	3.3	1.0	9.8	2.0	0.4	5.8	4
Lead	17	4.2	36	2.4	0.4	7.6	3.2[1)]
Cadmium	0.6	0.1	1.8	0.1	0.01	0.7	5
Chromium	9.5	2.1	20	1.9	0.4	4.5	10[1)]
Copper	87	20	239	7.7	1.8	27	12[1)]
Mercury	0.5	0.1	1.6	0.2	0.02	0.4	1
Nickel	12.5	3.3	34	7.3	1.7	20	160[1)]
Zinc	272	86	618	110	33	364	110[1)]

[1)] suggested quality objective.

Table 10.2 Mean values and fractiles for heavy metals in inlet and outlet of wastewater treatment plants, 1998-2002 and the nationally established quality objectives for fresh surface water. *Danish EPA, 2003; Ministry of Environment and Energy, 1996.*

AQUATIC ENVIRONMENT 2003 – Table 10.3

	LOOP (µg/l)	GRUMO (µg/l)	Waterworks (µg/l)	Limit value (µg/l)
Arsenic	0.2	0.8	1.3	5
Lead	0.6	0.05	0.2	5
Cadmium	0.1	0.008	0.02	2
Selenium	0.2	0.10	0.1	10
Nickel	6.0	0.5	2.0	20
Zinc	30	3.0	5.3	100
Copper	2.1	0.3	0.8	100
Chromium	0.2	0.09	1.0	20
Aluminium	1.9	2.1	5	100

Table 10.3 Median concentration of selected metals in the groundwater in LOOP, GRUMO and the waterworks' abstraction well control. The limit value for drinking water is "at property entrance". Further information is available in Annex 3.1, Annex 3.2 and Annex 3.3 in *GEUS, 2003* and information on limit values is available in *Ministry of Environment and Energy, 2001*.

AQUATIC ENVIRONMENT 2003 – Table 10.4

	LOOP (%)	GRUMO (%)	Waterworks abstraction wells (%)
Arsenic	9	16	16
Lead	31	1	1
Zinc	40	6	2
Nickel	51	6	3

Table 10.4 Exceedence of the limit values for drinking water for the period 1993-2002 (for LOOP, however, only 1998-2002). Percentage of analysed intakes with exceedence of the limit values in at least one analysis. *GEUS, 2003.*

Wastewater

The concentration of heavy metals in wastewater varies widely, depending on the type of industry connected to each individual treatment plant. The measured concentrations are of the same magnitude as those found in studies conducted by the Danish EPA in 1994 and 1996.

When comparing the wastewater concentrations of heavy metals with the stipulated quality objectives to be met by the aquatic environment, the outlet concentrations are generally on a level with or lower than the nationally specified quality objectives (Ministry of Environment and Energy*, 1996,* table 10.2). The measured discharge concentrations do not immediately raise concern in relation to the requirements established for the aquatic environment.

10.2 Status and trends

Groundwater

Groundwater monitoring of the concentrations of heavy metals comprises well screens in national groundwater monitoring areas (GRUMO) and agricultural watershed catchment areas (LOOP) as well as the waterworks' control of their water abstraction wells.

Opposed to GRUMO, the groundwater monitoring of LOOP is generally conducted in the uppermost groundwater. The LOOP monitoring comprises metals supposedly added to the newly formed groundwater from the surface, while the GRUMO monitoring also includes metals that occur naturally in groundwater or are found in deeper-lying groundwater as a results of human activities, such as lowering of the groundwater level.

The upper groundwater of LOOP is distinguished from the remaining groundwater by its higher content of zinc, nickel and copper, and to a lesser extent also lead (table 10.3).

Nickel, zinc and copper are among the metals found in high concentrations in organic fertilizers, particularly from pig farms (*Schwærter et al., 2003*). However, no existing investigations have certified the relationship between the high concentrations found in organic fertilizers and the uppermost groundwater.

A high nickel content is also found in the deeper-lying groundwater, as a lowering of the groundwater table may result in oxidation of sulphide minerals and thus release of nickel and other substances.

The groundwater's level of arsenic is among other factors determined by the redox conditions. This is because the arsenic content under reduced (oxygen-demanding) conditions is approx. 10 times higher than under aerobic conditions. This may explain the generally lower level of arsenic concentrations detected in the upper groundwater of LOOP than in GRUMO and in the waterworks' abstraction wells.

Generally, the limit levels for drinking water are exceeded in all monitoring programmes, i.e. both GRUMO, LOOP and the waterworks' control of abstraction wells. Thus, in the routine well controls exceedence of limit values was found for one or more inorganic trace elements in 35% of intakes during 1993-2000. The LOOP groundwater is characterised by more frequent exceedences of the limits set for drinking water (table 10.4).

For several heavy metals the quality objectives specified for surface water (*Ministry of Environment and Energy, 1996*) are lower than the limit levels set for drinking water. This means that the outflow of groundwater to watercourses, for instance spring brooks, may result in exceedence of the quality demands for watercourses, even though the heavy metal content is lower than the limit level for drinking water.

Marine areas

Monitoring of heavy metals in the marine environment in 2002 included mussels and fish.

The concentration of heavy metals in mussels in 2002 generally falls within the category of "slightly to moderately polluted" according to the Norwegian classification system elaborated by *Statens Forurensningstilsyn, 1997* (figure 10.2).

In the western part of Limfjorden the mercury content of mussels has, however, reached a level corresponding to "markedly polluted", and in Ringkøbing Fjord the concentrations of nickel and copper in sand mussels have also reached the "markedly polluted" level. As to Ringkøbing Fjord, however, it should be noted that the criterion applies to common mussels. The increased mercury level in the western part of Limfjorden appears in an area that has not hitherto been comprised by NOVA 2003, but with one known point source of mercury pollution (Cheminova).

The concentration of heavy metals in fish varies among sampling localities. Fish from the Sound generally have a mercury content that is a factor 2-3 higher than the national background specified by OSPAR (*OSPAR, 1998*). In the harbour of Copenhagen a mercury concentration exceeding the consumption limit value was found in a single flounder fillet.

AQUATIC ENVIRONMENT 2003 – Figure 10.2

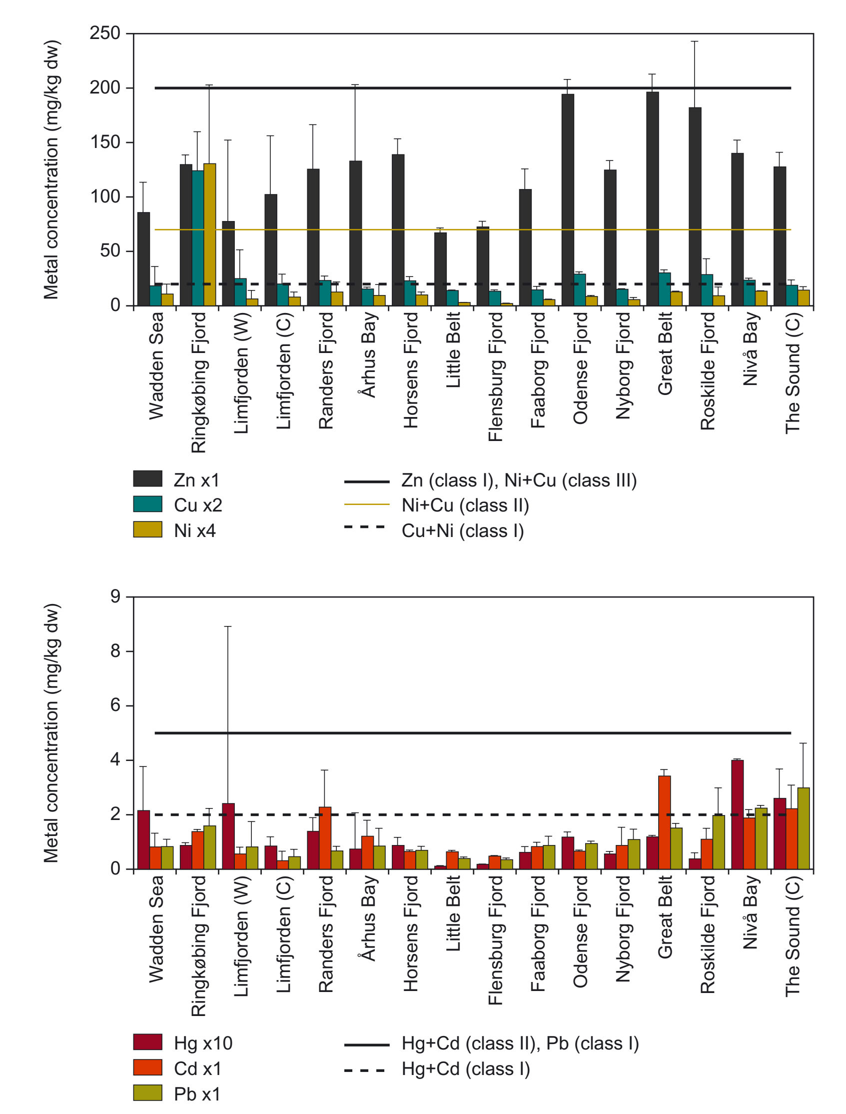


Figure 10.2 Metal concentrations (mg/kg dry weight) in mussels (average and maximum of 1 to 5 stations per area with 1-3 replicates per station) with lines indicating the limit for moderate (class 1) and significant (class II) pollution in SFT's classification. Notice: Hg, Cu and Ni are magnified in relation to the scale on the axis.
Rasmussen et al., 2003; *Statens Forurensningstilsyn, 1997*.

11 Pesticides

Pesticides are widely used for weed and pest control in farming and agriculture and in uncultivated areas. Not all pesticides are fully degraded having effected their purpose, and remains of pesticides and their metabolites are found scattered in the environment, particularly in groundwater.

In 2002 the monitoring of pesticides and their metabolites comprised wastewater from wastewater treatment plants, groundwater and streams.

The monitoring in groundwater and watercourses primarily concerns herbicides used in agriculture or forestry. The most frequent cause of pesticide pollution in groundwater is, however, BAM deriving from the degradation of dichlobenil (Prefix and Casoron G) and chlorthiamid (Casoron). These pesticides have been used for weed control in uncultivated areas, such as along roads and paths. These two pesticides are now banned.

Wastewater and sludge from wastewater treatment plants are investigated for the so-called drines (aldrine, dieldrine, andrine, isodrine) and lindane. All are chlorated pesticides whose use is no longer permitted. None of these pesticides have been found in either wastewater or sludge.

A survey of the pesticide monitoring programme can be found in *Danish EPA, 2000*.

11.1 Groundwater and streams

Groundwater in agricultural monitoring areas

Triazines (i.a. atrazine and simazine) and their metabolites have played a dominant role in both sub-surface groundwater in the agricultural monitoring catchments (LOOP) as well as in the deeper-lying groundwater and in streams. Among the 15 most frequently found pesticides and metabolites in LOOP and groundwater monitoring areas (GRUMO) and in watercourses, 6 triazines occur in LOOP, 6 in GRUMO and 4 in streams (figure 11.1).

Atrazine was last legally used in Denmark in 1994. Supposedly a pool accumulated in the root zone is now slowly being released. This may explain why atrazine and its metabolites are still found in streams and groundwater. In the agricultural monitoring areas various triazine metabolites have been found, with a weak trend towards increasing concentrations and frequencies (figure 11.2).

BAM, glyphosat and its metabolite AMPA as well as bentazon and mechlorprop are likewise among the most frequently detected pesticides and metabolites in groundwater, both

AQUATIC ENVIRONMENT 2003 – Figure 11.1

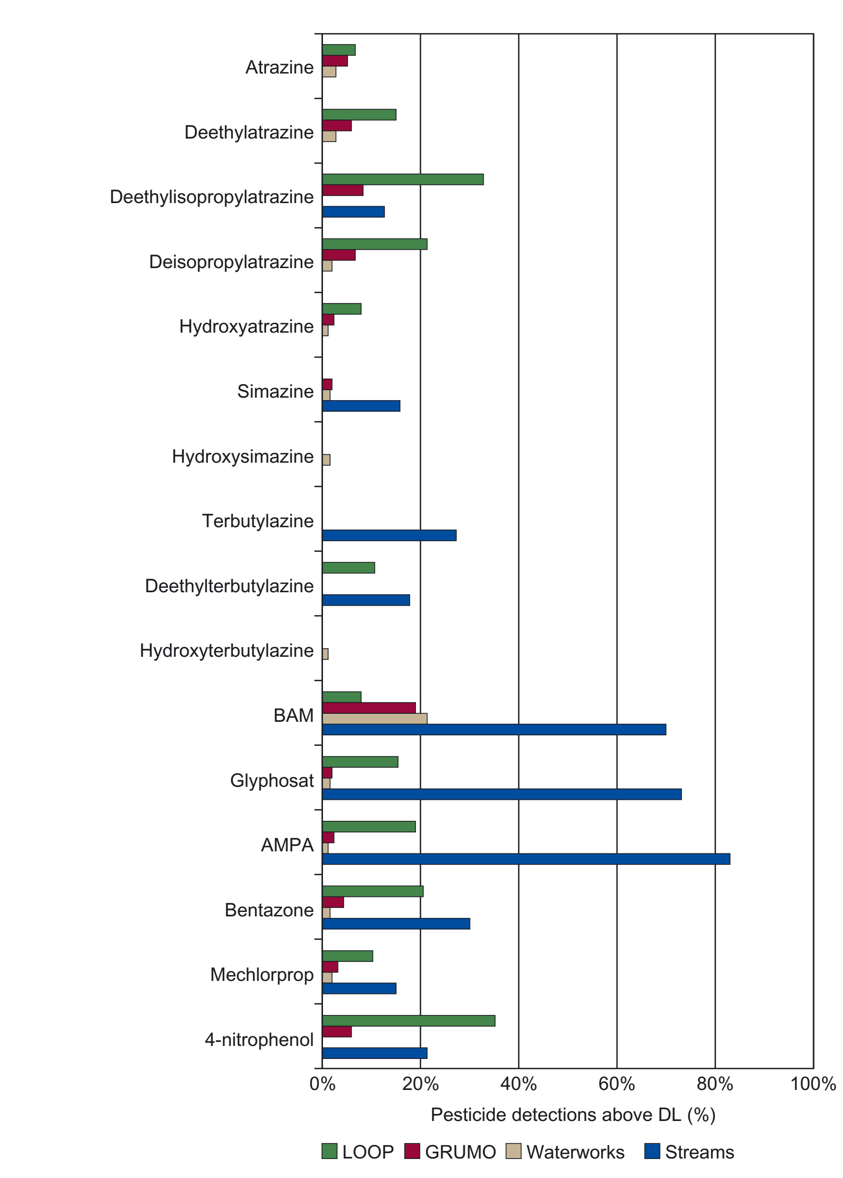


Figure 11.1 Detection percentages of frequently found pesticides in LOOP, GRUMO and waterworks' abstraction wells as well as streams. The groundwater percentage is calculated as % of analysed intakes where pesticides were detected (concentration above detection limit). The stream percentage is calculated as % of analysed samples showing pesticides.
GEUS, 2003 and *Bøgestrand (ed.), 2003*.

in LOOP and GRUMO monitoring catchments as well as in waterworks wells and streams. The use of glyphosat, bentazon and mechlorprop is still permitted, whereas dichlobenil is now banned (*Danish EPA, 2002*).

The depth distribution of the detected pesticides shows that sub-surface groundwater is the most vulnerable, but several detections have been made at > 30 m depth also (figure 11.3). During 1990-2002, pesticides were found in approx. 55 % of the intakes within the depth interval 0-10 m below ground level. The most frequent findings in sub-surface groundwater are particularly of BAM and the metabolites of triazines and phenoxy acids (mechlorprop, dichlorprop).

11.2 Exceedence of limit values

In all, pesticides were found in what corresponds to 37 % of the groundwater retrieved for drinking water production (approx. 33 % of the analysed intakes) in 2002. The limit value for drinking water was exceeded in 4% of these (i.e. 7% of the analysed intakes).

In GRUMO and waterworks wells, BAM was the most frequent cause of exceedence (7.5% and 6.6%). In LOOP, glyphosat was the most frequent cause (12.1%).

Danish discharge limit values have only been established for a limited number of pesticides. Based on the existing Danish standards and Dutch and Norwegian limit values, exceeded limit values for average concentrations in streams were found for 9 pesticides in 2002 (table 11.1). Terbutylazine and propiconazole are the substances most frequently observed to exceed limit values. Propiconazole is permitted for use in, for instance, grain growing, while terbutylazine is permitted for use in corn growing (*Danish EPA, 2002*).

Development

The frequency of intakes with detection of pesticide remains in 2002 is almost similar to that of previous years, both in groundwater monitoring areas and in waterworks wells. The 2002 frequencies were 27% and 33%, respectively. Also the frequency of intakes where the limit value for drinking water has been exceeded remains unchanged for the groundwater monitoring areas in 2002 compared with previous years.

AQUATIC ENVIRONMENT 2003 – Figure 11.2

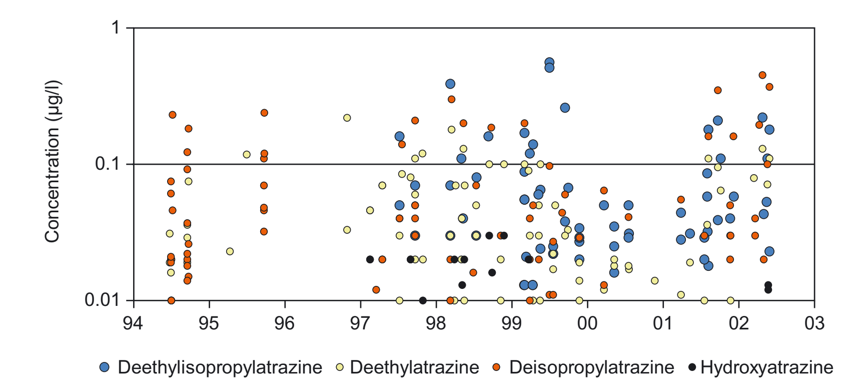


Figure 11.2 Selected triazine metabolites measured in water samples taken in July in 5 LOOP catchments. *GEUS, 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 11.3

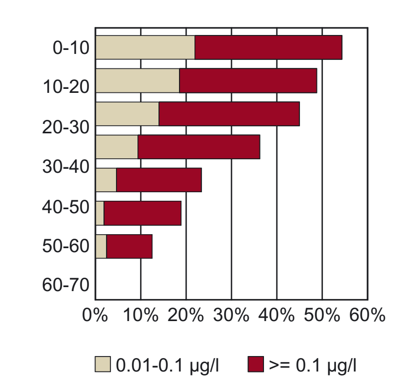


Figure 11.3 Pesticides and metabolites in groundwater samples taken at various water depths for the period 1990-2002. The youngest groundwater is primarily found at the interval 0-10 m below terrain where the number of intakes showing pesticides/metabolites is >50% for the period 1990-2002. Pesticides/metabolites were also found at >80 m depth, but as only few intakes were analysed these were omitted. *GEUS, 2003.*

AQUATIC ENVIRONMENT 2003 – Table 11.1

Pesticide	Number of detections	Number of exceedences	Max. values (µg/l)	Criteria (µg/l)	
Dinoseb	7	3	1.3	0.025	NL
Glyphosat	164	1	15	12	N
Isoproturone	67	4	2	0.3	N
Metamitrone	19	1	1.6	1.1	N
Primicarb	7	1	0.15	0.09	NL
Propiconazol	14	11	0.161	0.02	N
Terbutylazin	62	12	1.4	0.16	N
Trichlor acetic acid	103	1	2.4	1	DK
Trifluralin	1	1	0.1	0.037	NL
Total	**444**	**35**			

Table 11.1 Exceedences of the established pesticide criteria in streams in 2002. *Bøgestrand (ed.), 2003.*

12 Other organic environmental pollutants

Organic environmental pollutants include a number of substances figuring on the EU list of substances considered to have hormone-disturbing effects. Among these, especially nonylphenols, DEHP and bisphenol A have been in focus after the discovery of affected sexual organs and other effects on the reproduction system of fish in watercourses in Aarhus County (*Christiansen and Plesner, 2001*).

The group of other organic environmental pollutants than pesticides was included in the 2002 monitoring of wastewater, groundwater, streams and mussels from marine areas, examples being plasticizers, detergents (active ingredients), tars (PAH) and PCD. A survey of the monitoring programme on environmental pollutants is found in Danish EPA, 2000.

12.1 Sources

Wastewater

Wastewater is the primary source of environmental pollutants in the aquatic environment. Most substances are frequently found in the inflow to treatment plants, while only few substances are found in more than 25% of the analysed outflow samples (figure 12.1).

The substances most often found in the outflow are nonylphenols and phenol, the plasticizer DEHP, MTBE (a petrol additive), 2-methyl-naphthalene and P triesters. All of these substances were found in more than 50% of the analysed outflow samples.

None of the substances found in outflow from treatment plants had concentrations higher than the nationally established quality objectives for aquatic areas (*Danish Ministry of Environment and Energy, 1996*). However, quality objectives have not been established for all the substances included in the monitoring programme.

AQUATIC ENVIRONMENT 2003 – Figure 12.1

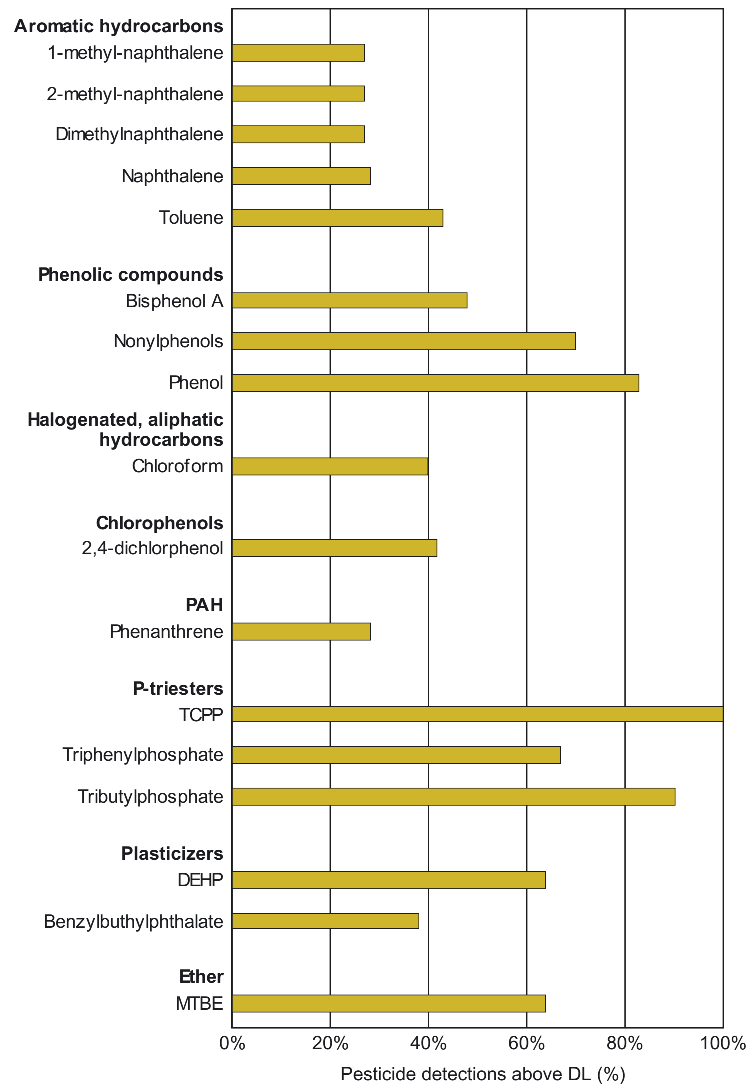


Figure 12.1 The detection percentage in outlet samples from wastewater treatment plants calculated as the number of samples with concentrations above the detection limit (DL) compared to the number of analysed samples. *Danish EPA, 2003*.

12.2 Status and trends

Streams

Among the investigated five watercourses, Damhusåen in Copenhagen stands out by the finding of selected environmental pollutants in more than half of the 12 annual samples. For these, the quantity transported to the sea via streams has been calculated. The substances are trichlorethylen, acenaphthene, fluoranthene, pyrene and LAS (table 12.1).

A number of substances (25) have not been found frequently enough to allow reliable calculation of the input to the sea.

Three of the 5 most frequently found substances are polycyclic aromatic hydrocarbons (PAH) deriving from the exhaust gas from cars and other combustion processes. Also in 2002 were these substances found frequently enough to permit calculation of transport, whereas calculation of nonylphenol and Benz(b)flour-anthene concentrations was no longer possible.

None of the substances found most frequently in the watercourses were among those most often found in the outflow from treatment plants.

Groundwater

In 2002, no major changes occurred in the concentrations of organic micropollutants compared with previous years (*GEUS, 2003*). However, the frequency of findings of organic micropollutants in the waterworks abstraction drill controls reached the average level of the previous period of 31%, compared to 23% in 2001. The frequencies established for each substance group were highest in the agricultural monitoring areas, whereas the frequencies of groundwater monitoring areas and waterworks wells remained relatively unchanged (figure 12.2).

Common for the findings in agricultural and groundwater monitoring areas and waterworks well controls is the fact that limit values were only exceeded in a few isolated cases, typically around or below 1% of the investigated well controls or intakes. The most frequently found substance to exceed the limit value was the plasticizer dibuthylphthalate (DBP) whose limit value was exceeded in 15.2% of the analysed intakes in the agricultural monitoring areas, and in 3.5% of the analysed intakes in the groundwater monitoring areas. Analyses for DBP were only made for a limited number of waterworks wells.

Marine areas

In the monitored Danish fjords and inner waters the detected concentrations of TBT in 2002 were so high that effects hereof are to be expected. In general, the concentrations of PCB and the other chlorinated compounds are lower, but still at a level that cannot be excluded to affect the environment.

The investigations of imposex and intersex (changes in sexual organs) as biomarkers for TBT showed that these phenomena were still widely discovered in four of the investigated species of sea snails in 2002. Particularly in harbours where the TBT level is expectedly highest, many periwinkles are sterile due to intersex. Several counties have made supplementary investigations of periwinkles, comprising both commercial and yachting harbours, allowing an evaluation of whether the problem is nationwide or not. As to whelks, high levels of imposex have also been found in many near-shore areas and, for the most vulnerable species, in open waters as well.

AQUATIC ENVIRONMENT 2003 – Table 12.1

Environmental pollutants	Number of detections	Mean values (µg/l)	Max. values (µg/l)	Annual transport (kg)
Trichlor-ethylene	12	0.285	1	3.479
Acenaphthene	6	0.0085	0.025	0.099
Flouranthene	7	0.0105	0.033	0.111
Pyrene	8	0.0115	0.031	0.115
Linear alkyl benzene sulphonate (LAS)	6	1.75	14	38.243

Table 12.1 Concentrations and transport in Damhusåen stream in 2002 of the most frequently detected environmental pollutants. *Bøgestrand (ed.), 2003.*

AQUATIC ENVIRONMENT 2003 – Figure 12.2

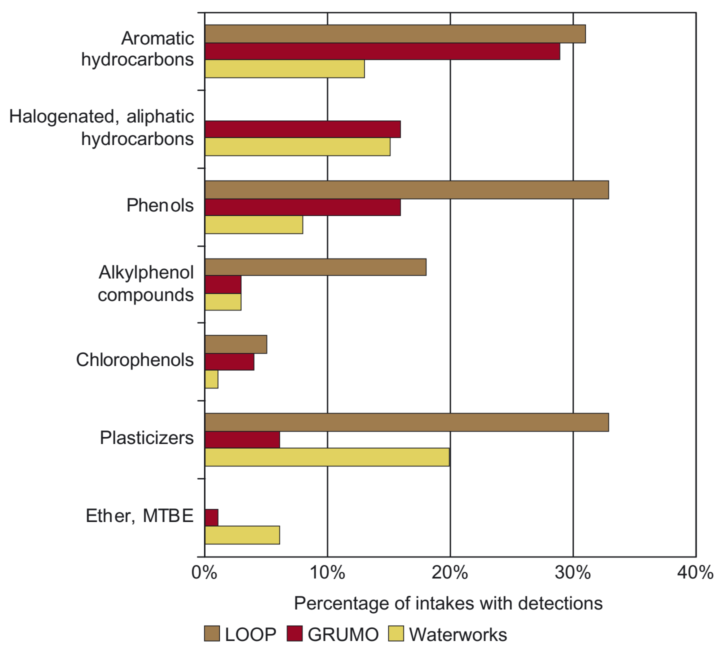


Figure 12.2 The detection percentage of other organic environmental pollutants divided into pollutant types for LOOP, GRUMO and waterworks' abstraction wells. The detection percentage for groundwater is shown at the number of intakes with findings (content above detection limit) compared to the number of analysed intakes. *GEUS, 2003.*

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