Ministry of Environment and Energy
National Environmental Research Institute

Aquatic Environment 2000

State and trends – technical summary

NERI Technical Report, No. 362

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Contents

1 Introduction

1.1 About this report

The present report "Aquatic Environment 2000. State and trends - technical summary" summarizes the results of the Danish Aquatic Monitoring and Assessment Programme 1998-2003, commonly referred to as NOVA-2003 *(Danish EPA, 2000b)*.

Overall content

"Aquatic Environment 2000. Status and trends - technical summary" provides the technical conclusions of the information gathered on the current state of impacts upon groundwater, watercourses and springbrooks, lakes, the atmosphere and the sea. The report summarizes the development in inputs of nutrients and hazardous substances from point sources and diffuse sources and transport to and within the aquatic environment. The trends in the quality of the aquatic environment in relation to changes in inputs are furthermore described. Finally, atmospheric deposition and trends in the concentration of different substances in the atmosphere are assessed.

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 Environment Protection Agency based on reports elaborated by the seven topic centres (*Bøgestrand (ed.) (2000), Ellermann et al. (2000), Grant et al. (2000), GEUS (2000), Hansen et al. (2000), Jensen et al. (2000) and the Danish EPA (2000c)*.

National topic centres

The national topic centres are responsible for the implementation of the monitoring programme within the following areas:

- Groundwater (GEUS)
- Point sources (Danish EPA)
- Agricultural catchment monitoring (NERI)
- Lakes (NERI)
- Watercourses (NERI)
- Atmospheric deposition (NERI)
- Marine waters (NERI)

Where do the data come from?

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 that are incorporated into the reports of the topic centres.

The purpose of this summary

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.

A political administrative report is prepared by the Danish Environmental Protection Agency and the National Forest and Nature Agency (*Danish EPA, 2000a*).

Structure of this summary

The report is centered around three main elements:

- One chapter (3) summarizing the trend in the input to the aquatic environment of nitrogen, phosphorus and organic matter from different sources, including delivery pathways from source to the aquatic environment. The chapter also encompasses nutrient leaching from the root zone and the factors influencing leaching.
- One chapter (4) summarizing the state and trend of the aquatic environment with focus on nitrogen and phosphorus concentrations and biological conditions and their interrelations within the aquatic environment.
- One chapter (5) summarizing the available results on heavy metals and hazardous substances in the aquatic environment, including a presentation of the results of discharges, concentration levels and impacts on biological components.

There is a short introductory description of climate and runoff conditions in 1999 (chapter 2) and a summary describing the principal results of the aquatic environment monitoring in 1999 (chapter 6).

1.2 NOVA-2003 Organisation and contents

Organisation of the nationwide aquatic environment monitoring programme

The majority of the monitoring is carried out by the county authorities. NERI is responsible for monitoring of the extensive marine stations, measurements and calculation of atmospheric deposition and the operation of a network of 27 national stations with time series going back to the 1920s for the determination of stream water flow.

For the purpose of ensuring the overall coordination of the programme and easing communication between the participating institutions, an appointed Programme Management Board decides on potential amendments or adjustments of the programme.

For the purpose of management and reporting, each of the seven topic areas is led by a topic centre that also implements the decisions made by the Programme Management Board. The topic centres are based at the National Environmental Research Institute, the Geological Survey of Denmark and Greenland, and the Danish EPA.

Each topic area has a steering committee (one joint steering committee for atmospheric deposition and marine waters) with the participation of the county authorities, the relevant topic centre and occasionally other sector research institutions, and one or more administrative agencies of the Ministry of Environment and Energy. The steering committees arrange topical meetings, evaluate the imple-

Tabel 1.1 Table showing the parameters investigated in the different subprogrammes under NOVA-2003. The analyzed substances are listed in the programme description of NOVA-2003 (*Danish EPA, 2000b*). *In lakes and marine waters, chemical analyses are performed in both water and sediment.

Investigated Parameters	Lakes	Water-courses	Ground-water	Agricultural catchment monitoring					Point sources	Marine	Atmo-sphere
				gw	lm	wa	dr	sw			
Catchment descriptions	x	x	x			x					
Catchment analyses	x	x				x					
Physical parameters:											
- oxygen and temperature	x	x	x	x					x	x	
- water quantity	x	x	x			x	x		x	x	x
- substance quantity	x	x	x			x	x		x	x	x
- age, soil physics			x								
Chemical parameters*:											
- nutrients	x	x	x	x		x	x	x	x	x	x
- org. matter, other param.	x	x	x	x			x	x	x	x	
- acidifying substances											x
- hazardous substances	x	x	x	x	x				x	x	
- heavy metals	x	x	x		x				x	x	x
- pesticides			x	x	x	x	x		x		
Biological investigations:											
- Phytoplankton	x									x	
- Zooplankton	x									x	
- Fish fry	x										
- Fish	x	x									
- Macrophytes	x	x								x	
- Macroinvertebrates		x				x				x	

gw = groundwater; lm =liquid manure; wa = watercourses; dr = drain, sw=soilwater

mentation and reporting of the programme and service the Programme Management Board on technical issues and refers to this Board.

Content of the monitoring programme

The contents of the various subprogrammes are briefly described below and summarized in table 1.1.

Groundwater

Groundwater is examined for content of substances, including pesticides and other hazardous substances, and for groundwater level and abstracted quantities. Hydraulic models for some monitoring areas are furthermore elaborated.

Point sources

Discharges from wastewater treatment plants, separate industrial dischargers, rain dependant discharges, freshwater fish farms, domestic discharge from catchment areas outside the sewerage system and from mariculture are determined. In the case of treatment plants and separate industrial dischargers, analyses for a number of nutrients and organic matter are performed.

Agricultural catchment monitoring

Five monitoring catchments are included in the agricultural catchment monitoring programme describing in detail cultivation practice, physical-chemical measurements in the root zone, chemical analyses of groundwater and liquid manure as well as biological investigations in the streams. Models describing water and nutrient transport are furthermore developed for a number of catchments in cooperation with the watercourse monitoring programme. In addition, the agricultural monitoring programme encompasses a number of other catchments with a less detailed programme.

Lakes

Lake investigations comprise an intensive programme for 31 lakes, including catchment descriptions, analyses of nutrients, hazardous substances and heavy metals, analyses of sediment nutrient conditions together with biological structure (phytoplankton and zooplankton, fish, macrophytes). In addition, a large number of lakes are extensively monitored for periods of 3 years.

Streams

The streams are generally investigated with respect to chemical composition, runoff conditions and transportation of nutrients and organic substances, and in some selected streams also hazardous substances and heavy metals. The total nutrient input to coastal areas is calculated. Investigations of macroinvertebrate communities for the determination of stream quality, and in selected localities also fish stock and vegetation, are further performed. In cooperation with the agricultural catchment monitoring programme, analyses are also performed with the purpose of determining, for instance, delivery pathways.

Atmospheric deposition

Nitrogen compounds, sulphur and heavy metals are measured and the atmospheric deposition is calculated by means of model calculations for the Danish waters and land areas.

Marine waters

Marine waters are examined with respect to chemical conditions in fjords and in open marine waters, in bottom sediment and in the organisms. Occurrence and composition of benthic invertebrates, algae and macrophytes and the amount of hazardous substances and heavy metals in fish are investigated. Oxygen conditions are measured to determine oxygen depletion. By means of models and numbers estimating the landbased input, the turnover of water and nutrients in inlets, and transport of water and nutrients in the open waters are calculated. Intensive investigations take place in 6 fjords (model fjords), at 16 marine stations and 6 automatic measuring buoys. Furthermore, 32 representative fjords and coastal areas as well as a number of less intensely monitored stations in the Danish waters have been selected. The National Forest and Nature Agency monitors macroalgae vegetation at 8 reefs. As from 2000, NERI has taken over these monitoring activities.

Further information on NOVA-2003

Further information on NOVA-2003 can be found on the homepage of the programme (http://NOVA.dmu.dk) where there is a complete description of the monitoring programme and links to the institutions participating in the monitoring of the Danish aquatic environment.

2 Water and Climate

2.1 Climate

Warm, wet and sunny

The weather in 1999 as a whole was characterized as being both very hot, very sunny, and unusually wet (table 2.1). A similar combination has never been seen before. The mean temperature of 8.9 °C was 1.2 °C above normal (1961-90) and 0.5 °C above the average of the monitoring period 1989-99. All months except June were warmer than usual. The 11 monitoring years have been 0.7 °C warmer than normal.

Precipitation

With 905 mm precipitation, 1999 was the wettest year at the national level since monitoring was initiated by the Danish Meteorological Institute in 1874, and it is 193 mm above normal. Precipitation was above normal during most months of 1999. Precipitation was only less than the mean in November. In the northern and northwestern part of Jutland and the central parts of southern and southwestern Jutland precipitation was between 1000 and 1200 mm in 1999, while the area of the Great Belt and the Baltic Sea only received 600-700 mm.

Irradiance and wind

The sun shone for 1,905 hours in 1999 compared with the normal of 1,670 hours (1971-90). The mean wind speed in 1999 of 5.5 metres per second at coastal stations was somewhat below the normal of 6.6 metres per second in spite of the strongest hurricane of the century occurring in December 1999.

Table 2.1 Annual mean temperature, precipitation, calculated potential water balance (adjusted precipitation minus potential evaporation) and freshwater runoff. Winter values are mean values for the period from, for instance, December to March. Source: *Bøgestrand (ed.) (2000)* and *the Danish Meteorological Institute*.

	Temperature		Precipitation		Water balance	Runoff		
Period	Annual °C	Winter °C	Annual mm	Winter mm	Potential mm	Annual mm	Annual 10^6 m^3	Winter mm
1989	9.2	4.7	581	210	131	252	10800	133
1990	9.3	4.7	812	271	420	322	13900	151
1991	8.2	2.1	654	197	317	296	12700	154
1992	9.0	3.5	706	208	280	294	12600	129
1993	7.6	2.4	758	199	413	325	14000	155
1994	8.7	1.8	880	360	524	455	19600	259
1995	8.2	2.8	652	337	245	363	15600	246
1996	6.8	-1.6	505	70	129	190	8200	68
1997	8.5	1.4	622	153	244	207	8900	104
1998	8.2	3.5	860	243	561	362	15600	136
1999	8,9	2,1	905	277	585	427	18400	204
1989-99	**8.4**	**2.5**	**721**	**229**	**350**	**318**	**13600**	**158**
1961-90	7.7	0.9	712	207	336	326*	14000*	159*

* the normal is here 1971-90.

2.2 Freshwater runoff

Freshwater runoff in 1999

Total freshwater runoff from Denmark in 1999 was approx. 18,400 million m^3 corresponding to 427 mm (table 2.1). The annual runoff was thus 31% above the mean runoff for the period 1971-1999 of 326 mm. The runoff was at the same time 34% above the mean for 1989-99. In comparison, precipitation in 1999 was 27% above the normal and 26% above the mean for 1989-99. Especially in the winter months of January and March and in particular December, runoff as well as precipitation were exceptionally high.

Geographic variations

Runoff conditions and precipitation were subject to large geographic variations in 1999, as there was generally correspondence between freshwater runoff and (net) precipitation. However, the groundwater aquifers also have an effect on these patterns. From the catchments of the marine waters in the southern Belt Sea, the Baltic Sea and the Sound freshwater runoff was only approx. 200-250 mm, while runoff to marine waters in the North Sea was between 500 and 600 mm.

The climate in 1999 provided the potential for severe diffuse nutrient loading to the aquatic environment

The high precipitation has resulted in an equally high runoff from cultivated areas and has provided a potential for considerable soil and bank erosion causing a relatively severe diffuse loading of nitrogen and phosphorus to the aquatic environment in 1999. Runoff towards the end of 1999 has provided the potential for a relatively high diffuse input of water and nutrients to the aquatic environment during this period and for a period of 2000. The hurricane in December 1999 resulted in a complete stirring of the water column in most marine areas.

2.3 Water balance

Connection between precipitation, runoff and the groundwater table

Generally, there is a good correspondence between precipitation and runoff (figure 2.1). Runoff is, however, somewhat delayed when compared to precipitation because part of the precipitation leaches into the ground and to primary and secondary aquifers, before it reaches the watercourses. During dry years, runoff relative to precipitation is often higher than expected, because the groundwater aquifers are depleted as it happened in, for instance, 1989 and 1995 (table 2.1 and figure 2.1). During wet years, part of the precipitation will fill up the groundwater aquifers, and the runoff will be lower than expected as it happened in 1990 and 1998 (table 2.1 and figure 2.1). During and after dry years the groundwater table decreases while it increases during and after wet years.

The hydrological cycle

The various parts of the hydrological circle are illustrated in figure 2.2 for Jutland and the islands. It is assumed that there were no considerable changes in the groundwater aquifers during the long water balance determination period. The water balance shows that the runoff is only 205 mm on the islands while it is 370 mm in Jutland due to lower precipitation and slightly increased evaporation. Runoff conditions in streams on the islands are consequently more easily affected than in Jutland. Dried-out watercourses during summer are also typically found in Zealand, especially in places with significant water abstraction.

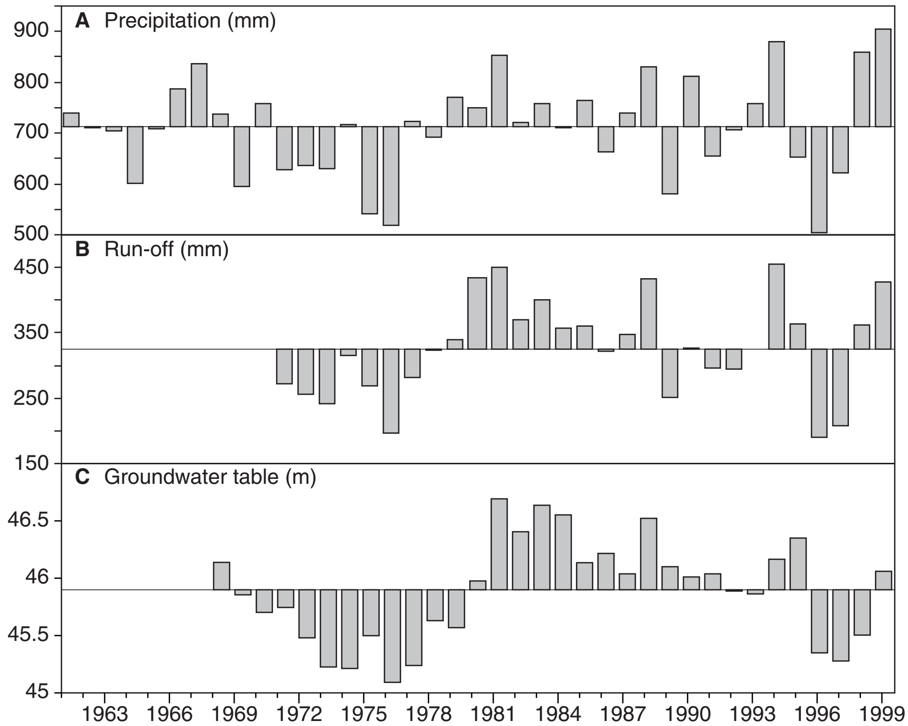

Figure 2.1 Annual mean precipitation (A), total runoff from Denmark (B) and annual mean groundwater table at Karup (C) for the period 1961-1999 in relation to the average of the periods 1961-90 (A), 1971-90 (B) and 1968-90 (C). Sources: *Bøgestrand (ed.) (2000)*, *Danmarks Meteorologiske Institut* and *GEUS (2000.)*

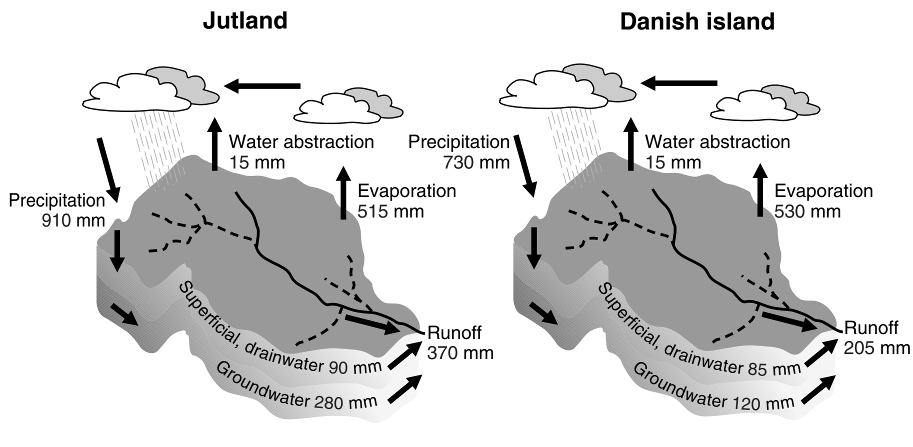

Figure 2.2 The hydrological cycle, including water balance values, for the period 1971-98 in Jutland and the islands. The individual links are independently assessed. Precipitation is adjusted according to the soil surface. Source: *Ovesen et al. (2000)*.

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3 Sources and discharges of nitrogen, phosphorus and organic matter to the aquatic environment

3.1 Introduction

Types of sources

Discharge sources of nutrients, organic matter, heavy metals and hazardous substances to the aquatic and air environment are divided into point sources and diffuse sources. Point sources include discharges from:

- wastewater treatment plants
- separate industrial dischargers
- freshwater fish farms
- stormwater outfalls
- sparsely built-up areas
- mariculture

Diffuse sources include discharges from:

- cultivated areas
- uncultivated areas
- atmospheric deposition

Content of this chapter

This chapter provides an overview of point source discharges in 1999 and shows the trend in discharges from these sources together with technical information about the sources. Loss from cultivated areas and information of agricultural practice are also reviewed, as is the input of nitrogen and phosphorus to lakes, streams and coastal marine areas. Discharges of organic matter are usually measured as biological oxygen demand for a period of 5 days (BOD_5), which is a measure for mineralized organic matter.

3.2 Point sources

3.2.1 Wastewater treatment plants in 1999

Number of plants

In 1999, there were 1,447 municipal and 262 private wastewater treatment plants in Denmark. 277 of the municipal plants are subject to the requirements of the Danish Action Plan on the Aquatic Environment as to extensive removal of nutrients and organic matter. 90% of the wastewater is treated in these plants. There has been a tendency towards fewer but larger plants and in 1999, 25 of the largest plants treated almost half of the total amount of the wastewater (table 3.1).

Plant types

In 1999, 274 plants were able to perform the most extensive form of treatment, i.e. mechanical and biological purification, nitrification and denitrification and removal of phosphorus. These plants treated 85% of the total amount of wastewater. In 1989, there were only 59 plants of this type that treated 10% of the total amount of wastewater. The private plants are small mechanical or biological plants treating less than 2% of all wastewater.

Table 3.1 Distribution of wastewater treatment plants by size and share of total load on the various plant sizes. Plants >100.000 PE are responsible for 44% of the load, plants >50.000 PE for 63% of the load. Source: *Danish EPA (2000c)*.

Plant capacity	Number of plants	Load in % of the total plants
> 30 PE	1409	100%
> 500 PE	708	99%
> 2,000 PE	461	97%
> 5,000 PE	273	92%
> 15,000 PE	130	82%
> 50,000 PE	60	63%
> 100,000 PE	25	44%

Capacity

The total treatment capacity in 1999 was 12 million PE calculated as the capacity of the wastewater treatment plant to remove organic matter (1 PE is 60 g BOD_5 per day). In 1999, the total load on all plants was 8.1 million PE.

Water input

The total water input to the treatment plants in 1999 from households, industry, rainwater and water infiltrating into the sewers was calculated at 825 million m^3. The magnitude is affected by the amount of precipitation and was therefore relatively high in 1999. Based on the information from 755 plants, the Danish EPA estimates that the total infiltration into the sewers in 1999 was 29% of all wastewater input to wastewater treatment plants *(Danish EPA 2000c)*.

Discharges from wastewater treatment plants in 1999

In 1999, the total discharge from wastewater treatment plants to freshwater and directly to coastal areas was 825 million m^3 wastewater containing 5,104 tonnes nitrogen, 581 tonnes phosphorus and 3,508 tonnes BOD_5.

Treatment efficiency in 1999 was 90% for phosphorus and organic matter and more than 80% for nitrogen at plants applying the most comprehensive method of purification.

3.2.2 Separate industrial dischargers in 1999

Number of separate industrial dischargers

For 1999, the county authorities have reported 150 enterprises with outlets to lakes, watercourses or coastal areas. 100 of these enterprises have discharged nitrogen, phosphorus and/or organic matter, and 58 of these heavy metals and/or hazardous substances. 38 of the enterprises are encompassed by the requirements of the Action Plan on the Aquatic Environment to reduce nutrient discharges. Some of these enterprises still discharge untreated wastewater. The calculations do not encompass discharge from enterprises that discharge less then 30 PE.

Discharge from separate industrial dischargers in 1999

In 1999, the discharge from separate industrial dischargers was approx. 65 million m^3 wastewater. The total discharge of wastewater in 1999 was 863 tonnes nitrogen, 69 tonnes phosphorus and 9,528 tonnes BOD_5. Between 75 and 90% of the discharge in 1999 derives from enterprises encompassed by the requirements of the Danish Action Plan on the Aquatic Environment. 41% of the total nitrogen and phosphorus discharge derives from the fish processing industry.

3.2.3 Stormwater outfalls in 1999

What are stormwater outfalls?

Stormwater outfall encompasses all outlets to the aquatic environment from roofs, roads, paths and squares connected to a sewerage system. The discharges are divided into separate discharges of surface water and overflow from combined sewerage systems where the discharge consists of a mixture of surface runoff and wastewater.

Reporting methods

Stormwater discharges are usually calculated on the basis of general values based on experience and reported by the Danish EPA in 1990 of 2 mg l^{-1} nitrogen, 0.5 mg l^{-1} phosphorus and 50 mg l^{-1} COD (a measure describing organic matter measured with an oxygen consuming substance). The calculations for overflow discharges from combined sewerage systems have improved during the 1990s in connection with the revision of wastewater plans, digitalisation of sewerage system etc., although the calculation methods applied still vary.

Number of plants

In 1999, there was a total of 12,232 stormwater plants, of which 5,021 were combined systems and 9,211 separate discharges of surface runoff. 2,901 of the plants had a holding basin for reduction of the overflow discharge to the aquatic environment. The total catchment area of the plants constituted almost 240,000 ha of which more than 70,000 ha were paved areas. In 1999, there were holding basins on the drainage systems from 37% of the paved area serviced by combined sewerage systems and 35% of the total paved area with separate sewerage systems, but there are distinct regional differences.

Stormwater discharges in 1999

Stormwater discharges follow the level of precipitation and with the record breaking amount of precipitation in 1999 the discharge was equally high, approx. 20% higher than for a normal year. 249 million m^3 water containing 975 tonnes nitrogen, 251 tonnes phosphorus and 2,839 tonnes BOD_5 was discharged.

The sewage load from stormwater owerflows usually constitutes only 1-4% of the total sewage load from wastewater treatment plants for nitrogen, phosphorus and organic matter, but the proportion of the water volume is about 2-8%.

3.2.4 Freshwater fish farms in 1999

Freshwater fish farms – number and location

Freshwater fish farms (with the exception of eel farms) mainly raise rainbow trout. All freshwater fish farms are situated on watercourses in Jutland and 75% of the production takes place in the counties of Ringkjøbing, Ribe, Vejle and Nordjylland. The county authorities have reported 406 fish farms in 1999 out of which 381 were in operation. In 1989, there were 510 registered freshwater fish farms.

Feed consumption and production

Relative to other enterprises freshwater fish farms are generally relatively small and for 70% of the farms the legal annual feed consumption is less than 100 tonnes per year. Only 6% of the fish farms are allowed an annual feed consumption exceeding 200 tonnes. 65% of the total production derives from fish farms with a legal feed consumption of more than 100 tonnes. In 1999, 32,703 tonnes fish (wet weight) and 31,055 tonnes feed was consumed. Consequently, the feed coefficient (number of kilo fish produced per kg feed used) was 0.95.

Discharge from freshwater fish farms in 1999

Discharge from fish farms is calculated theoretically on the basis of feed consumption and fish production. In 1999, there was a discharge of 1,127 tonnes nitrogen, 83 tonnes phosphorus and 3,056 tonnes BOD_5.

3.2.5 Scattered dwellings in 1999

What are scattered dwellings?

Rural settlements comprise discharges of less than 30 PE and include houses located in summer cottage districts, allotment cabin districts, sparsely built-up areas, and villages. In 1999, there were 348,000 properties of which scattered dwellings constituted 59%, summer cottages 31% and villages 7%.

Reporting methods

Three knowledge levels are applied for the determination of discharge from scattered dwellings *(Danish EPA, 2000c)*. Since 1989, the calculation methods have been regularly amended in accordance with the current knowledge level on scattered dwellings.

Types of sewage treatment

Apportioned by type of sewage treatment, 37% of the properties have soakaways with drains, 12% have soakaways without drains, 7% are considered as being without discharge and 44% are others with discharge. Properties with mini treatment plants and root zone plants constitute a total of approx. 1% of the properties.

Total discharge from scattered dweelings in 1999

The discharge from scattered dwellings is somewhat related to the amount of precipitation. In 1999, the total discharge from scattered dwellings constituted 12 million m^3 wastewater, 971 tonnes nitrogen, 221 tonnes phosphorus og 3,813 tonnes organic matter.

3.2.6 Mariculture in 1999

Sea-based and land-based fish farms

Mariculture comprises both farming of fish in sea-based fish farms and land-based fish farms fed by seawater raising primarily rainbow trout. Sea-based fish farms are "breeding farms with net cages, wire boxes or similar placed in coastal areas and where the breeding requires consumption of feed". Salt-water fish farms are "breeding farms placed on land with intake of salt water, including cooling water from power stations or similar, where breeding requires consumption of feed".

Number of enterprises

In 1999, a total of 13 land-based fish farms were fed by seawater and there were 25 seawater fish farms. The seawater fish farms are mainly situated in the inner Danish marine waters. The majority of the land-based mariculture fams are located close to the coast in Ringkjøbing county and the rest are situated in the counties of Viborg and Vestsjælland.

Discharge from land-based mariculture fish farms in 1999

In 1999, the discharge to the sea from land-based fish farms fed by seawater was 301 tonnes nitrogen, 35 tonnes phosphorus and 1,616 tonnes BOD_5.

3.2.7 Total discharge from point sources in 1999

Wastewater discharges to freshwater, and direct wastewater discharges

In 1999, the total discharge from point sources to the aquatic environment constituted 9,371 tonnes nitrogen, 1,238 tonnes phosphorus and 24,336 tonnes BOD_5 (table 3.2). 60% of the total wastewater

Table 3.2 Wastewater discharge from point sources in 1999. Source: *Danish EPA (2000c)*.

	Inland waters			Marine			Total		
Tonnes	N	P	BOD_5	N	P	BOD_5	N	P	BOD_5
Wastewater treatment plant	2,705	258	1,682	2,429	324	1,826	5,134	581	3,508
Separate industrial dischargers	38	3	47	825	66	9,481	863	69	9,528
Stormwater plants	752	195	2,169	223	56	670	975	251	2,839
Freshwater fish farms	1,127	83	3,032	-	-	-	1,127	83	3,032
Scattered dwellings	966	220	3,795	5	1	8	971	221	3,813
Mariculture	-	-	-	301	35	1,616	301	33	1,616
Total	5,588	759	10,725	3,783	482	13,601	9,371	1.238	24,336

discharge of nitrogen was discharged into freshwater. 61% of the phosphorus discharges and 44% of BOD_5 discharges from point sources were discharged into freshwater.

Significance of the individual point sources

For both nitrogen and phosphorus, discharges from wastewater treatment plants were the greatest point source to both freshwater and coastal marine waters. Phosphorus discharge to freshwater from scattered dwellings was, however, an almost equally important point source with 29% of the discharge. Scattered dwellings was the major source of discharge of BOD_5 (35%), while discharge from fish farms (28%) and stormwater outfalls (20%) were other important sources. Separate industrial dischargers were the major point source of BOD_5 to coastal marine waters in 1999 constituting 70% of the total load. 11% of BOD_5 point source discharges to coastal areas in 1999 derived from mariculture. Thus freshwater fish farms and mariculture farms are important sources in the areas where they are situtated.

Section 3.4 compares the discharge from point sources with discharges from other sources.

3.2.8 Trend in point-source discharge

Significant reduction in discharge from wastewater treatment plants and separate industrial dischargers

Since 1989 there has been a reduction in the total point source discharge of 66% for nitrogen, 81% for phosphorus and 74 for organic matter measured as BOD_5 (figure 3.1). The reduction in nitrogen and phosphorus discharge was primarily a result of marked reductions in wastewater plant discharges and separate industrial discharges due to improved wastewater treatment. Discharges from wastewater treatment plants containing nitrogen, phosphorus and organic matter were reduced by 74%, 90% and 94%, respectively. The corresponding figures for discharges from separate industrial dischargers are 85%, 95% and 84%. The reduction targets in the Action Plan on the Aquatic Environment I regarding discharge from wastewater treatment plants and separate industrial dischargers have been met since 1996-97.

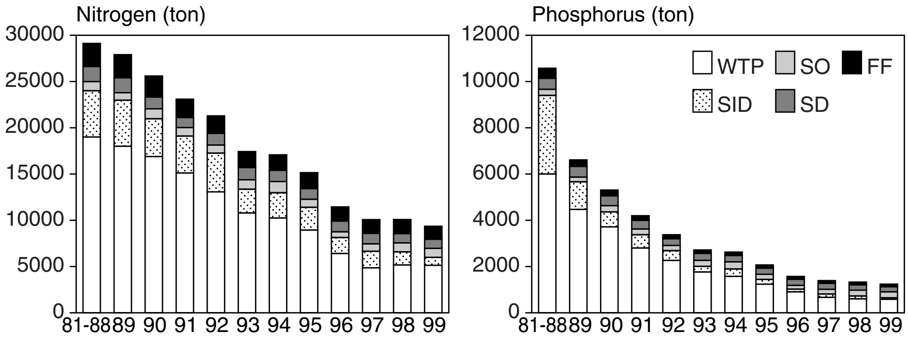

Figure 3.1 Annual discharges from point sources expressed as the sum of discharges to freshwater and direct discharges. WTP=wastewater treatment plants, SID=separate industrial dischargers, SO=stormwater outfalls, SD=scattered dwellings, FF=fish farms (freshwater and mariculture). Sources: *Danish EPA (1999b); Bøgestrand (ed.) (2000) and Danish EPA (2000c).*

Scattered dwellings and fish farms

A reduction in discharge from scattered dwelling has taken place between 1989 and 1999. The reduction in phosphorus is mainly attributable to the use of phosphate-free detergents.

There has been a reduction in the total discharge from freshwater fish farms since the late 1980s of 49%, 59% and 55%, respectively, for nitrogen, phosphorus and BOD_5. Phosphorus discharge from sea-based fish farms has fallen since the late 1980s, whereas discharges of nitrogen and phosphorus have been at the same level for some years.

3.3 Quantification of diffuse sources

3.3.1 Introduction

This section deals with diffuse sources and delivery pathways of nutrients. There is a presentation of the main results of the monitoring of the agricultural catchments. These small catchments have been monitored for farming practices, nitrogen and phosphorus balances as well as loss from the root zone and drains for a number of years. Part of the loss of, for instance, nitrogen from the root zone will reach the groundwater and eventually also the streams, while another part will reach the streams relatively rapidly via drains, macropore flow and the unsaturated zone. The root zone loss in the agricultural monitoring cathments is related to farming practices and is used partly for the assessment of the effect of changes of these practices and partly to assess the progress in relation to the reduction targets of the Danish Action Plans on the Aquatic Environment. In section 3.4.3, the root zone and drain loss of nitrogen and phosphorus are related to the stream transport in the catchments.

3.3.2 Atmospheric deposition

Measurements and model calculations of deposition

The atmospheric deposition is determined on the basis of data from 8 monitoring stations, meteorological data, emission calculations and modelling (*Ellermann et al., 2000*).

Nitrogen deposition in 1999

Nitrogen deposition to Danish fjords, inlets and bays was averagely 11 kg ha^{-1} in 1999. Nitrogen deposition is highest on the landmass with more than 20 kg ha^{-1} in some areas in Jutland with many livestock, and lowest with 9 kg ha^{-1} on the Skagerrak and the western part of the North Sea (*Ellermann et al., 2000*). As a whole, deposition on marine waters decreases from the south towards the north with little deposition on the sea far from the coasts. In 1999, the total nitrogen deposition on Danish marine waters (97,700 km^2) was calculated at 120,000 tonnes and 90,000 tonnes on Danish land areas (43,100 km^2). The total deposition of 210,000 tonnes corresponds fairly well with the total estimated emission in 1998 of 160,000 tonnes.

Sources of nitrogen deposition

Nitrogen deposition on Danish marine waters derives equally from agriculture (approx. 40%) and combustion processes (approx. 60%). However, the combination of sources depends on regional conditions. More than 50% of the deposition on Limfjorden and the Kattegat, for example, derives from agricultural sources while the remaining deposition derives from various combustion processes. Of the total deposition on Danish marine waters, the contribution from Danish sources constitutes 28% on the Kattegat, 9% on the North Sea, and more than 40% on coastal areas. The average Danish contribution amounts to 15% of the total atmospheric nitrogen input to the Danish marine waters.

Seasonal variation in wet deposition

The seasonal variation in most nitrogen compounds is related to the variation in emissions, physical and chemical transformation, atmospheric transport and seasonal variation in precipitation. The seasonal variation in nitrate during the period 1989-99 was not significant, but the deposition reflects the variation in precipitation. The deposition of ammonia reflects largely the ammonia concentration in the atmosphere, which is highest in summer.

Uncertain nitrogen deposition

The estimated uncertaincy of the nitrogen depositions calculated by the models is 30-40% for the open marine waters and 40-60% for coastal marine waters. The estimated uncertainty factor of the annual deposition on the landmass is up to 2. The application of the improved model should provide more accurate results, but a single year is too slender a basis for assessing whether the improved correspondence between measurements and calculations for 1999 is coincidental.

Trend in nitrogen deposition

As the wet deposition of nitrate (and ammonium) relates to, for example, the amount of precipitation, it shows marked interannual variations (figure 3.2). In 1999, wet deposition amounted to approx. 80% of the total nitrogen deposition. There has been a non-significant fall in nitrogen deposition.

Phosphorus deposition

Phosphorus deposition is primarily bound to particles. The total input to the inner Danish marine waters is estimated at a maximum of 255 tonnes in 1999 corresponding to 0.08 kg/ha.

Sulphur

Sulphur in the atmosphere is primarily sulphur dioxide and particulate sulphur. The dry deposition of compounds has decreased markedly during the period with 70-90% for sulphur dioxide and 46-73% for particulate sulphur. There is a corresponding marked fall in the wet deposition of sulphate of 33-51%. Much of the sulphur dioxide and the particulate sulphur is transported to Denmark from the northern parts of the European continent. The reduction in sulphur deposition is therefore attributable to a reduction in sulphur emissions both in Denmark and the rest of Europe due to, for example, improved flue gas abatement measures.

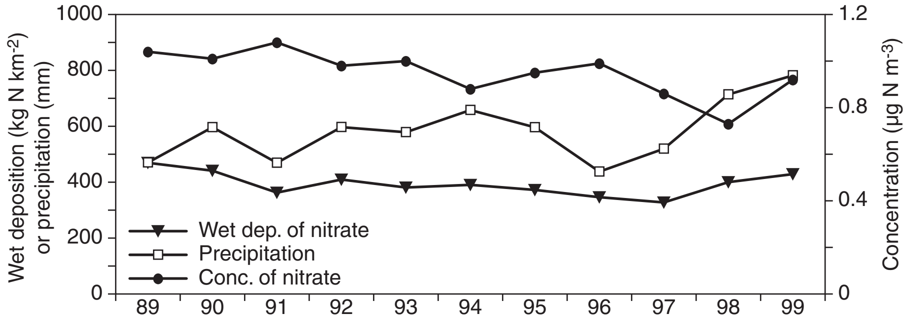

Figure 3.2 Sum of nitrate concentration, wet deposition, annual precipitation as an annual average for the Anholt monitoring station. Source: *Ellermann et al. (2000).*

3.3.3 Loss of nutrients from the root zone and via drains in cultivated areas

3.3.3.1 Agricultural monitoring catchments

Representativity of catchments

The selected agricultural monitoring catchments reflect the country average as to soil, climate, size distribution, livestock density, farm type distribution, and crop distribution, but the catchments are obviously not identical to the country average for certain parameters. The catchments are considered to reflect the country average as to agricultural practice of the various farm types. (*Grant et al., 2000*).

3.3.3.2 Trend in fertilization consumption for the country as a whole

Nitrogen consumption and fertilization practice for the country as a whole, 1985-1999

Since 1990, the total consumption of nitrogen fertilizer has been decreasing. The consumption of commercial fertilizer in particular has decreased from 392,000 tonnes N in 1985 to 257,000 tonnes N in 1999. There is also a slight reduction in nitrogen from manure (without binding) (approx. 16,000 N). The total nitrogen input to cultivated areas has been reduced by 24% from 606,000 tonnes N in 1985 to 463,000 tonnes N in 1999.

Nitrogen balance for agricultural land in Denmark, 1985-1999

The total nitrogen input to agricultural land in Denmark, including commercial fertilizer, livestock manure and nitrogen input from the N-fixation by leguminous plants and atmospheric deposition, has fallen from 744,000 tonnes N in 1985 to 572,000 tonnes N in 1999. Nitrogen removed by harvesting has varied between 308,000 and 408,000 tonnes N. The nitrogen surplus has thus been reduced from 374,000 tonnes N in 1985 to 227,000 tonnes N in 1999. During the entire period there has been a reduction of 37%. In 1999, about 20% of the area was excessively fertilized, but there has been a marked decrease in the magnitude of excessive fertilization.

Number of livestock

The number of livestock units in Denmark has remained fairly constant since 1990. The ratio of cattle to pigs has changed, however, so that pigs now account for 49% while cattle account for 46%.

Phosphorus balance for Danish agricultural land, 1985 - 1999

The input of phosphorus from commercial fertilizer per unit area agricultural land in Denmark has fallen from 47,6000 tonnes P in 1985 to 19,300 tonnes P in 1999, while the input of phosphorus from livestock manure increased from 48,200 tonnes P to 54,7000 tonnes P during the same period. The increased phosphorus input from livestock manure is partly a result of an increase in the manure norms in 1997. Phosphorus removed by harvesting has varied between 46,900 tonnes P and 62,600 tonnes P. The phosphorus surplus to agricultural land has thus been reduced from approx. 42,500 tonnes P to 29,000 tonnes P from 1985 to 1999.

3.3.3.3 Trend in agricultural practice in the agricultural monitoring catchments

Trend in agricultural practice in the agricultural monitoring catchments, 1990 - 1999

70% of the cultivated area consists of winter green fields. Of this, grass including set-aside, winter rape and undersown cereals account for 41%, winter cereals for 41% and root crop, maize, fields with ploughed-in stubble and spruce for 18%. Only the first group and root crops (sugar beet) can be expected to take up significant amounts of nitrogen in the autumn and winter months. In 1999, 85% of the livestock units were located at farms with at least 9 months' manure storage capacity. The percentage livestock manure applied in spring and summer increased by 31 percentage points from 1990 to 1999 and includes a decrease of 5 percentage points from 1997 to 1999.

Input of nirogen to the agricultural monitoring catchments, 1990 - 1999

The reduction in the consumption of commercial fertilizer from 1990 to 1998 resulted in an increase in the utilization of manure by 42 percentage points, but in 1999 the utilization was reduced, mainly due to the reduced norms for utilization. The livestock manure was applied in a more appropriate manner in 1994-1999 than previously, mainly due to the extensive use of trailing hoses. Approx. 14% of the farms that used livestock manure in 1999 did not comply with the requirements on utilization of livestock manure as they had an average of approx. 15% of the land. Improved utilization of livestock manure requires a further reduction in the consumption of commercial fertilizer.

3.3.3.4 Nutrient leaching from the agricultural monitoring catchments

Nurient leaching from the root zone has been investigated at 18 field stations in 3 clayey soil catchments and 14 field stations in 2 sandy soil catchments (prior 1998 there were a further 8 stations in a third sandy soil catchment). The study covers 10 hydrological years.

Nitrogen leaching from the root zone

Average nitrogen leaching from the root zone during the study period constituted 73 kg N ha^{-1} $year^{-1}$ in 3 clayey soil catchments and 133 kg N ha^{-1} $year^{-1}$ in one sandy soil catchment (see figure 3.4 in section 3.4.3.2). There is a great variation in precipitation related leaching (see figure 4.4 in chapter 4).

Nitrogen concentrations in soil water

A statistical analysis for the period 1990/91-1998/99 shows a fall in the measured nitrogen concentrations in the soil water as an average for groups of monitoring stations. Determination of the reduction is subject to some uncertainty because of the small number of monitoring stations and the uncertainty of the impact of the climate conditions.

Phosphorus leaching from the root zone

Average phosphorus leaching from the root zone was low (0.065 kg P ha^{-1} $year^{-1}$) during the 10-year measurement period. At 1/6 of the stations, however, concentrations were higher than average.

Phosphorus loss via drains

The average phosphorus loss via drains constituting 66% of the leaching from the root zone was 0.043 kg P ha^{-1} $year^{-1}$. About half of the loss was dissolved ortophosphate.

Drainage water studies in two clayey soil catchments indicate that nitrate leaching via drains constituted approx. 43% of leaching from the root zone.

3.3.3.5 Model calculations of nitrogen leaching from the root zone

Nitrogen leaching from the root zone will be reduced

An empirical model has been used to calculate leaching from the root zone in the agricultural monitoring catchments. The model is designed to reflect differences between clayey soil catchments and sandy soil catchments as well as differences in agricultural practice. Calculations of current agricultural practice from 1990/1991 to 1998/99 show that nitrogen leaching from the cultivated areas of the catchments as a whole will be reduced by 28% over a period of years.

3.3.4 Natural background loss

What is the natural background loss?

The natural background loss is the loss of, for instance, nitrogen and phosphorus that would exist if there were no human activity in the catchment. The natural background loss is calculated on the basis of measurements in small, uncultivated rural catchments characterized by very low cultivation intensity and lack of point sources.

Natural background loss of nitrogen and phosphorus in 1999

The high precipitation in 1999 resulted in a relatively high average background loss of 3.3 kg N ha^{-1} and 0.130 kg P ha^{-1}. During the period 1989-98, the corresponding input has varied between 1.3-4.3 kg N ha^{-1} and 0.034-0.136 kg P ha^{-1}.

3.4 Inputs and sources to inland and marine waters

3.4.1 Introduction

This chapter examines input and sources of nitrogen, phosphorus and organic matter to inland and marine waters. The atmospheric deposition on the sea is included in the calculation of the total input to marine waters.

3.4.2 Input to lakes

Due to the record-high precipitation in 1999 the water input to the lakes was considerably greater than normal with short residence times as a result. Input of nitrogen and phosphorus was higher in 1999 than in 1998 and for phosphorus it exceeded the 1994-98 average (table 3.3).

Table 3.3 Table showing retention times, hydraulic load, inflow concentration of nitrogen and phosphorus for 16 lakes during the monitoring period 1989-1999. Adapted from *Jensen et al. (2000).*

		Average	25 %	Median	75 %
Retention time (T_w)	1989-93	0.707	0.064	0.241	1.006
	1994-98	0.903	0.084	0.248	1.520
	1999	0.465	0.046	0.190	0.609
Water input (q_s)	1989-93	18.1	4.6	15.4	23.4
	1994-98	18.8	5.3	16.8	23.3
	1999	22.9	7.2	21.6	29.9
Inflow concentration	1989-93	7.98	5.93	8.27	10.77
(mg N l^{-1})	1994-98	6.28	4.92	6.52	7.88
	1999	5.84	4.48	6.19	7.54
Nitrogen input	1989-93	400	165	406	551
(mg N m^{-2} d^{-1})	1994-98	349	147	350	520
	1999	401	167	345	580
Inflow concentration	1989-93	0.239	0.107	0.137	0.211
(mg P l^{-1})	1994-98	0.120	0.089	0.112	0.138
	1999	0.123	0.092	0.105	0.127
Phosphorus input					
(mg P m^{-2} d^{-1})	1989-93	12.0	2.5	6.7	11.2
	1994-98	7.0	2.5	7.1	10.7
	1999	9.7	3.1	7.1	11.8

Sources

Input from cultivated areas and the natural background loss were the most important input sources of both nitrogen (78%) and phosphorus (73%) to the monitored lakes in 1999. The point source contribution was modest, and the most important point source, scattered dwellings, contributed with 4% nitrogen and 17% phosphorus. The contribution of both nitrogen and phosphorus from wastewater treatment plants and separate industrial dischargers decreased from approx. 22% in 1989 to approx. 3% in 1999 as a result of improved wastewater treatment methods.

Atmospheric deposition

The atmospheric deposition plays an important role in places where the lake surface in relation to the total catchment is large.

15 kg N and 0.1 kg P ha^{-1} were used for the calculation of the atmospheric deposition. The calculations of atmospheric deposition on lakes are, however, subject to some uncertainty. The average atmospheric deposition in 1999 is estimated at 16% of the nitrogen input and 7% of the phoshporus input to the monitored lakes.

3.4.3 Input to inland waters in the monitored catchments

3.4.3.1 Transport in watercourses in the agricultural monitoring catchments

High runoff in 1998/99

Runoff was high in 1998/99 when compared with the average of the previous 9 years.

New hydrological model reveals that more water derives from the unsaturated zone

An analysis of the hydrographs for the streams in the 5 agricultural monitoring catchments shows that much of the runoff to watercourses occurs in the unsaturated zone, especially in the clayey catchments, rather than via the groundwater. The runoff in the unsaturated zone is rapid and constitutes 40-57% of the total runoff to watercourses in the clayey catchments and 43% in the sandy catchments.

The total average nitrogen input to the watercourses from cultivated areas during the study period was 25.9 kg N ha^{-1} $year^{-1}$ in clayey catchments, and 11.3 kg N ha^{-1} $year^{-1}$ in sandy catchments. In comparison, the nitrogen loss from uncultivated rural catchments was 1.3-4.3 kg N ha^{-1} $year^{-1}$ during the study period.

Similar phosphorus loss from clayey and sandy catchments

During the measurement period the total loss of phosphorus from cultivated areas to watercourses calculated on the basis of normal sampling was averagely 0.36 kg P ha^{-1} $year^{-1}$. No clear difference is apparent between the clayey catchments and the sandy catchments. In comparison, the phosphorus loss from uncultivated rural catchments was 0.03-0.14 kg P ha^{-1} $year^{-1}$ during the same period.

Phosphorus loss was previously underestimated

Intensive monitoring of the phosphorus transport in the watercourses in the agricultural monitoring catchments in 1998/99 reveals that the phosphorus loss during that period was approx. 20% higher than the result achieved by the ordinary method of random sampling.

3.4.3.2 Nitrogen transport in the hydrological cycle in the catchments

A large part of the leached nitrogen reaches the watercourses in clayey catchments

Nitrogen transport in 3 clayey catchments and 2 sandy soil catchments was estimated on the basis of measurements and calculations for the 10 hydrological years 1989/90 - 1998/1999 (figure 3.3). In the clayey soil catchments there is an annual net input to the fields of approx. 81 kg N ha^{-1}. Leaching from the root zone is calculated at approx. 74 kg N ha^{-1}, of which approx. 35% has reached the watercourses. The annual net input to the sandy soil catchments is approx. 145 kg N ha^{-1}. Leaching from the root zone was measured at approx. 138 kg N ha^{-1} of which approx. 8% has reached the watercourses. Consequently, there is a build-up of nitrogen in the soil.

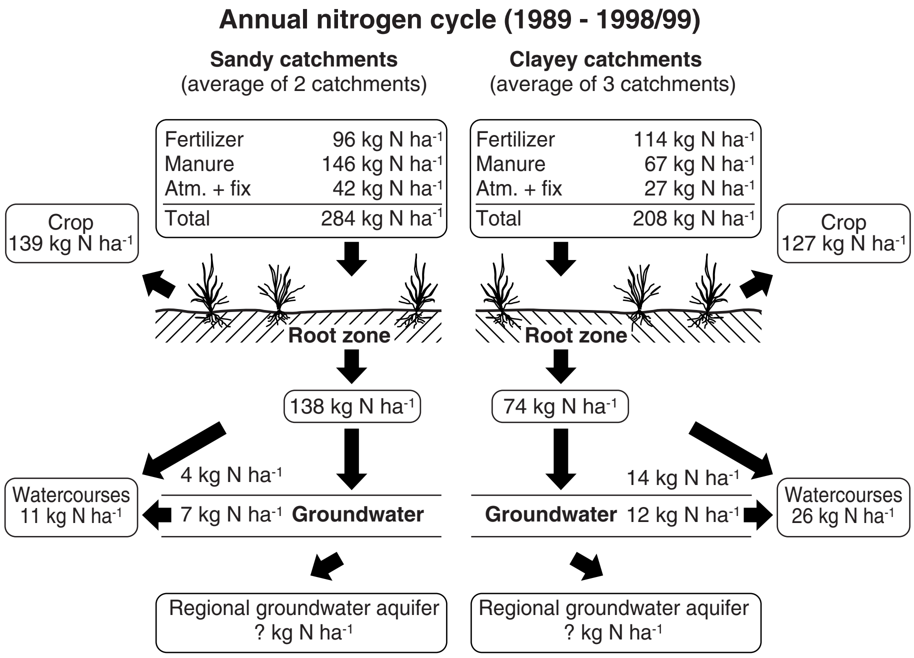

Figure 3.3 The nitrogen cycle in clayey soil catchments and sandy soil catchments from 1989/90 –1998/99. Source: *Grant et al. (2000)*.

3.4.4 Input to marine waters in 1999

Input to watercourses and springbrooks

The total input of nitrogen, phosphorus and organic matter to freshwater in 1999 constituted 106,000 tonnes nitrogen, 2,650 tonnes phosphorus and 33,000 tonnes BOD_5, when the retention in freshwater of nitrogen and phosphorus was taken into account. The input of both nitrogen and phosphorus was relatively high as a result of the high runoff in the watercourses.

Input to the sea

The nutrient input to coastal areas comprises input via watercourses, which can be divided into diffuse contribution from the open land, including scattered dwellings and direct discharge to the sea, including mariculture. The input to the sea encompassed 101,500 tonnes nitrogen, 3,060 tonnes phosphorus and 46,600 tonnes BOD_5 in 1999. The total input to Danish marine waters (not including input from bordering waters, biological N-fixation etc.) is calculated by adding the atmospheric deposition. The total input was in 1999 221,500 tonnes nitrogen and 3,800 tonnes phosphorus and more than 46,600 tonnes BOD_5 (table 3.4).

Table 3.4 Input to the sea via Danish watercourses, direct Danish discharges and atmospheric deposition on Danish marine waters in 1999. The diffuse runoff includes discharge from scattered dwellings. Adapted from Bøgestrand (ed.) (2000), Danish EPA (2000c) and Ellermann et al. (2000).

	Nitrogen	Phosphorus	BOD_5
Via watercourses			
- diffuse runoff	93,100	2,050	26,100
- point sources (excl. sparsely built-up areas)	4,600	540	6,900
Via watercourses, total	**97,700**	**2,590**	**33,000**
Direct discharge incl. mariculture	3,800	470	13,600
Total input to coastal areas	**101,500**	**3,060**	**46,600**
Atmospheric deposition on the sea (1)	120,000	750	not known

(1) Rough estimate for phosphorus

Input pathways and input sources of nitrogen and phosphorus

The atmospheric deposition on Danish marine waters is not immediately comparable with the land-based Danish inputs to coastal waters because only 15% of the atmospheric deposition on the sea derives from Danish sources. There is furthermore an input of nutrients to Danish marine waters deriving from the neighbouring countries and fixation of nitrogen also takes place. On the other hand, some of the nitrogen that is emitted from Denmark is deposited on territories belonging to other countries. Atmospheric deposition is the most important input pathway of nitrogen to Danish open marine waters.

Delivery pathways and sources of nutrients to coastal marine waters

Atmospheric deposition on freshwater is included in the diffuse runoff when the input to Danish coastal marine waters is calculated (table 3.4). 96% of the nitrogen input to coastal areas in 1999 came via streams. The corresponding figures for phosphorus and organic matter were 85% and 71%, respectively. The input from cultivated areas was the predominant source of nitrogen (81%) and phosphorus (45%) to coastal marine waters. Inputs from point sources constituted 8% of the nitrogen input and 38% of the phosphorus input. The remaining part of the nitrogen input (11%) and the phosphorus input (17%) is natural background loss in which also atmospheric deposition is included.

Diffuse input to freshwater from major sources

The nitrogen input from cultivated areas to streams and lakes in 1999 was 84%, while the input from the natural background loss was 11% and the input from wastewater 5%. The corresponding figures for phosphorus input are 53%, 19% and 28%, respectively. In a wet year, such as 1999, the nutrient loss from cultivated areas will be higher than in dry years, this is especially the case for phosphorus. Stormwater discharges and discharges from scattered dwellings constitute 7% and 8%, respectively, and are thus fairly important sources of phosphorus discharge to freshwater.

3.4.5 Trend and source of input to coastal marine waters

Input of diffuse nitrogen and phosphorus is closely related to runoff

The input of nitrogen to coastal marine waters during the period 1989-1999 is positively correlated with the freshwater runoff. The corresponding phosphorus input has been steadily decreasing throughout the period with a tendency, however, towards higher input during years with high runoff (figure 3.4).

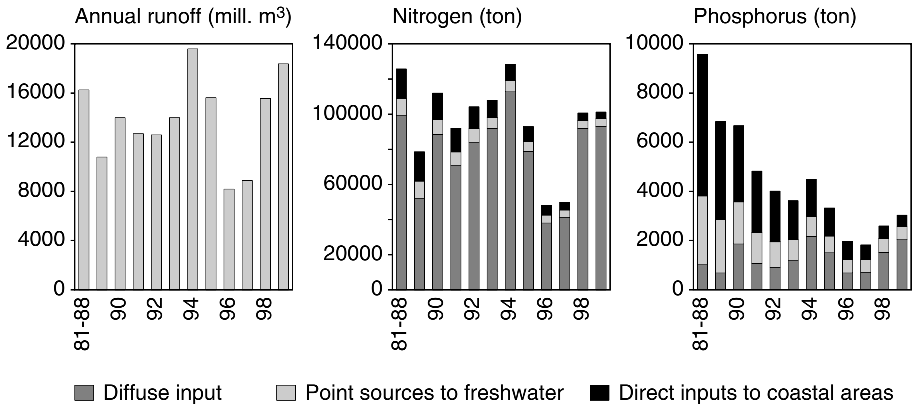

Figure 3.4 Annual freshwater runoff and annual nitrogen and phosphorus input to coastal areas in Denmark. Source: *Bøgestrand (ed.) (2000).*

Table 3.5 Total calculated nitrogen deposition to Danish waters from 1989 to 1998. Unit: tonnes nitrogen. Source: *Ellermann et al. (2000).*

Name	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
All Danish marine waters	93,000	105,000	93,000	90,000	77,000	90,000	79,000	85,000	96,000	105,000	120,000

This is due to the diffuse input of both nitrogen and phosphorus being higher in wet than in dry years. The total input of nitrogen to Danish marine waters is calculated by adding the figures for nitrogen in table 3.4 to the figures in table 3.5 describing the calculated atmospheric nitrogen deposition plus the input from other waters, nitrogen fixation etc.

Wastewater discharge significantly reduced

As previously mentioned there has been a significant reduction in point source discharges as a whole (section 3.2.7). There was a corresponding reduction in wastewater discharges to freshwater of 51% for nitrogen and 76% for phosphorus. Diffuse sources are thus becoming increasingly important and the diffuse sources have been the main phosphorus source since 1998. Relatively, the diffuse sources are becoming an even more important source of nitrogen.

Significant reduction in nitrogen and phosphorus input to Danish coastal marine waters ascribed to reduced wastewater discharges

There was a significant reduction in the total input of both nitrogen and phosphorus to coastal areas and almost all marine waters. An analysis of the input from diffuse sources, including discharge from scattered dwellings, alone shows a non-significant decrease in the input of nitrogen to 8 Danish main marine waters and a significant decrease in the input to the Litlle Belt. On average, there is no significant increase in the diffuse input of phosphorus. The reduced inputs are thus ascribable to improved wastewater treatment.

Effect of changed agricultural practices will not be evident for many years to come

The reduction in nitrogen leaching from the root zone calculated on the basis of the agricultural monitoring catchments is now gradually being reflected in the diffuse inputs to coastal marine waters. It might take some years before the full effect of new agricultural practices on the nitrogen input to the sea will be evident and the interannual variations caused by climatic conditions will exceed the reduction in the overall nitrogen input level for some time.

Diffuse phosphorus input

The reduction in discharges from scattered dwellings has not been reflected in the diffuse phosphorus input, rather quite the reverse. It is, however, difficult to assess whether this is due to climatic variation or an actual increase in phosphorus input from cultivated areas.

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4 State of the aquatic environment - status and trends

4.1 Groundwater

4.1.1 Groundwater abstraction

Status

The Danish water supply is predominantly based on groundwater, with more than 99% of the water supply consisting of water abstracted from groundwater aquifers. A modest volume of surface water is used as water supply in only two places. The supply of drinking water is decentralized and based on public common waterworks. In addition, there are a number of local individual water supplies for commercial watering (i.e. field irrigation, market gardens and freshwater fish farms) and for other purposes (industry, institutions, households and remedial action pumping).

In 1999, a total of 683 million m^3 groundwater was abstracted. The wet summer of 1999 meant that the abstraction for field irrigation and market gardens declined with 16% compared to 1998, 1998 being the year with the lowest consumption during the 1989-1998 period (figure 4.1).

Trends

The abstraction by waterworks decreased with 34% during 1989-1999, while that of industry increased with 9% during the same period. Lowering of the groundwater table and remedial action pumping represent almost one fifth of industrial abstraction. No calculations exist of surface water abstraction prior to 1997.

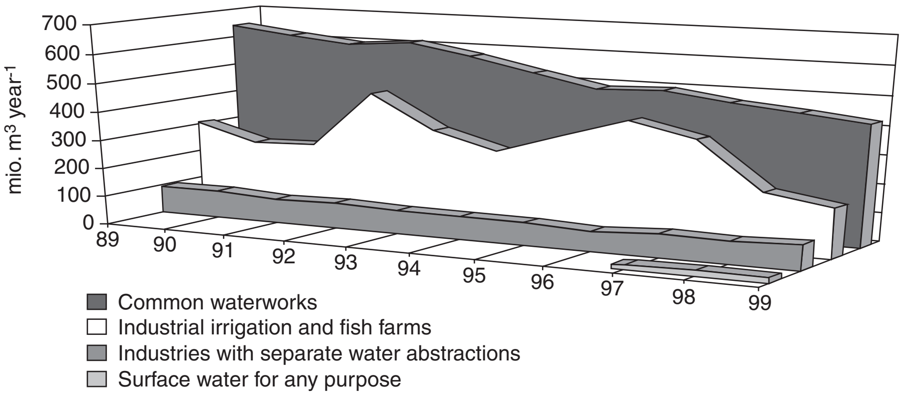

Figure 4.1 Water abstraction in Denmark in 1989-1999 (million m^3 yr^{-1}) divided into categories - based on reports from GEUS and in monitoring reports elaborated by the Danish counties. Source: *GEUS (2000).*

4.1.2 Groundwater monitoring

Monitoring stations

Evenly distributed throughout the country there are 67 groundwater monitoring areas, supplemented with approx. 17 monitoring filters divided into primary groundwater body, upper "secondary"

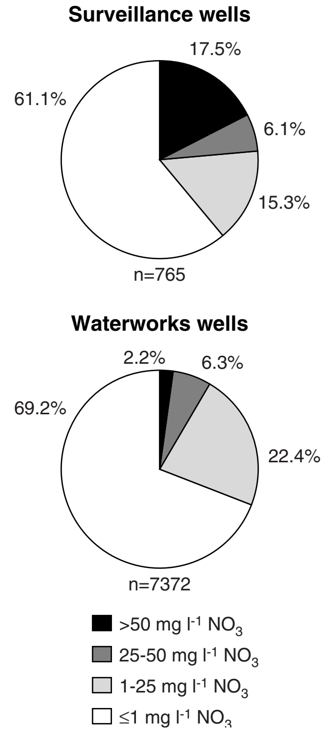

Figure 4.2 Nitrate concentrations (mg l^{-1}) in line-monitoring filters in groundwater monitoring (upper) and waterworks abstractions (lower). Median value 1993-99. Source: *GEUS (2000).*

groundwater body and one abstraction well. In addition, data from the waterworks abstraction well control are included.

Monitoring of groundwater comprises approx. 1,040 filters applicable for identifying the main components of groundwater. Most filters are moreover used for analysis of inorganic tracers, pesticides and other organic micro-pollutants. About 100 filters placed in the groundwater in the five agricultural monitoring catchments are, among other things, used for monitoring the quality of the newly formed subsurface groundwater.

In 1997-98, age determination was performed on the groundwater from 790 filters, where earlier investigations had shown that the water was young. The conclusion of the age determination was that only 10% of the groundwater in the monitoring areas has been formed after the adoption of the Action Plan on the Aquatic Environment. The objective of the plan to reduce nitrogen leaching is therefore not expected to be reflected in the current monitoring results.

4.1.3 Nitrate and phosphorus

The nitrate concentration was unchanged in 1999 compared to 1998. Data from the period 1989-1999 show that 61% of the monitoring filters and 69% of the waterworks abstraction wells do not contain nitrate. In approx. 24% of the monitoring filters in the monitoring catchments, the nitrate concentrations exceed the guide level for drinking water of 25 mg l^{-1} and 17% exceed the limit value of 50 mg l^{-1} (figure 4.2). The nitrate concentration was higher than 25 mg l^{-1} in only 8% of the waterworks abstraction wells, and above 50 mg l^{-1} in 2% of the wells (figure 4.2). This is due to the closure of many wells with high nitrate concentrations.

Nitrate concentrations are low on the islands, while the highest levels (>25 mg l^{-1}) are found in Jutland in particular (figure 4.3).

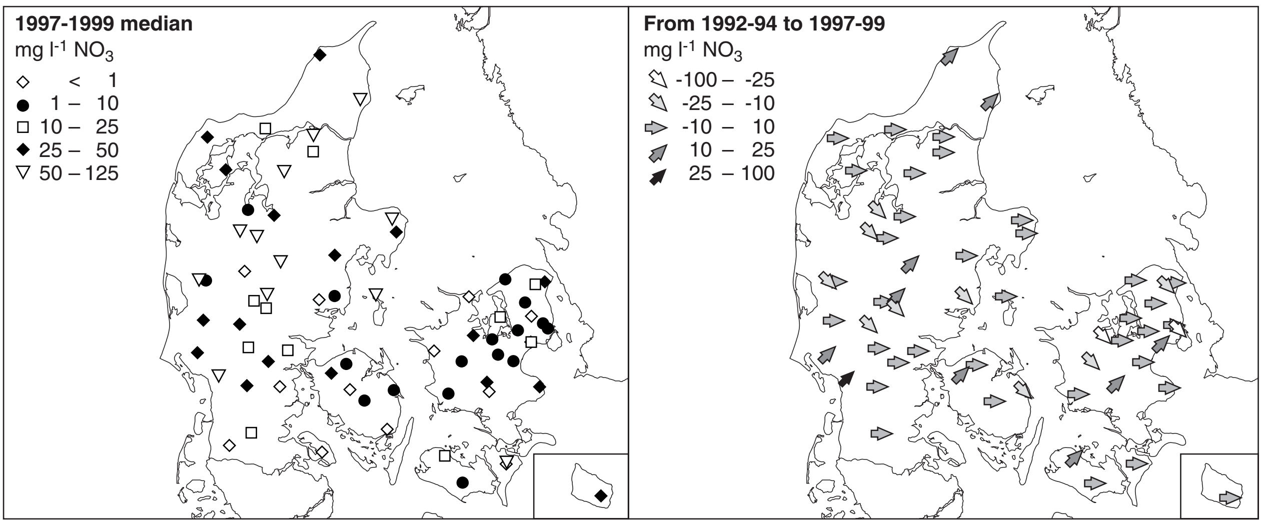

Figure 4.3 Nitrate concentrations in 1997-1999 (left) and nitrate development from 1992-1994 to 1997-1999 (right) in groundwater monitoring areas with concentrations above 1 mg nitrate l^{-1} (median values). Source: *GEUS (2000).*

In the upper subsurface groundwater aquifers, changes in the groundwater concentrations of i.a. nitrate may be conditioned by annual variations in the groundwater table. Thus, it may be difficult to determine if a minor decrease in nitrate concentrations is due to reduced leaching from agricultural soils, or whether it is caused by changes in the groundwater table and, with it, subsequent changes in the groundwater flow direction. On a national basis there is generally still no effect of the monitoring programme on the groundwater concentration of nitrate to be detected, as most of the groundwater monitored is older than 1987 when the Action Plan was adopted.

In the agricultural monitoring catchments, investigations show that the nitrate concentration in the upper aquifers is still high. The average nitrogen concentration in 1999 was ca. 12 mg N l^{-1} in sandy catchments (corresponding to 50 mg nitrate l^{-1}) and ca. 5 mg N l^{-1} in clayey soils. In 1999, the groundwater nitrate concentration was lower than in 1997 and 1998. Despite significant annual variations, leaching from the root zone has decreased since 1990/91. For sandy soils, opposed to clayey soils, leaching from the root zone can be detected in the upper aquifers (figure 4.4).

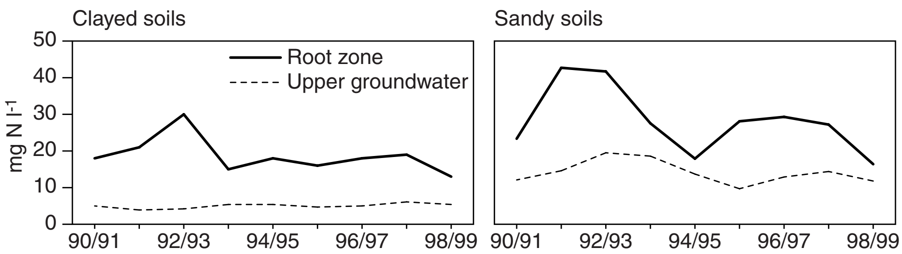

Figure 4.4 Development in the flow-weighted nitrogen concentration in root zone water (ca. 1 m below surface) and in the upper groundwater between 1.5 and 5. m subsurface in, respectively, 3 clayey and 2 sandy soils comprised by the agricultural monitoring catchment programme, 1990/91-1998/99. Source: *Grant et al. (2000).*

During the monitoring period, no general tendency towards either a decrease or increase in the nitrate concentration in the uppermost aquifers was recorded.

Phosphorus - status

In 1999, more than 0.15 mg phosphorus per litre (the limit value for drinking water) was recorded in 109 of 657 filters in the monitoring areas. In waterworks abstractions, the phosphorus concentration was higher than 20% in 1,608 wells. High phosphorus concentrations are more frequently found in wells where the water has been in contact with phosphorus-rich marine sediments.

As the majority of the phosphorus is removed from the water during routine treatment it does not generally comprise a problem for the consumers. However, phosphorus may be a problem for small waterworks without any form of water treatment.

Phosphorus - development

Despite local variations in the phosphorus concentration of groundwater during the monitoring period 1990-1999, the concentration remains comparatively constant, as it is primarily attributable to the geological conditions.

4.2 Lakes

4.2.1 Physical characteristics of lakes

Monitoring lakes

In Denmark, there are around 120,000 lakes greater than 100 m^2, of which only 2,762 are larger than 10,000 m^2. A total of 31 lakes are encompassed by the monitoring programme. They are selected so as to represent all Danish lake types and span from pure, clearwater lakes to lakes strongly polluted by existing outlets or earlier sewage inputs. Four of the lakes are brackish.

The size of the lakes ranges between 0.1 km^2 and 39.9 km^2, with an average of 3 km^2. Mean depths vary between 0.6 m and 16.5 m, with an average of 3.6 m. Both lakes situated in natural catchments with very low nutrient inputs and lakes receiving diffuse nutrient inputs from agriculture and scattered dwellings, as well as lakes heavily polluted by point sources, are included.

4.2.2 Nitrogen and phosphorus retention

In 1999, the water supply was much higher than normal, cf. section 3.4, table 3.3, which meant that lake retention times were shorter than in most other monitoring years.

Nitrogen retention

Relative nitrogen retention in lakes decreases with decreasing residence time. Due to changes in the fish stock composition and unrelated to changes in hydrological conditions, nitrogen retention increased in some of the monitored lakes which have shifted to a clearwater state. In half of these lakes, nitrogen retention in 1999 was greater than 26%. Average absolute nitrogen retention was 111 mg N m^{-2} d^{-1}, corresponding to 405 kg N ha^{-1} y^{-1} (table 4.2).

Phosphorus retention

Phosphorus retention in the monitoring lakes is not as closely correlated with lake retention time and was, in 1999, less than 8% in half of the lakes. In about one third of the lakes, the phosphorus balance was negative, i.e. the lakes released more phosphorus than they received due to release of phosphorus from the lake sediment after the loading reduction.

Table 4.2 Nitrogen and phosphorus retention in 1999 shown as annual average. According to *Jensen et al. (2000).*

		Mean	25 %	Median	75 %
Retention	1989-93	122	60	113	164
(mg N $m^{-2}d^{-1}$)	1994-98	98	35	81	129
	1999	111	50	93	160
Retention (%)	1989-93	32.6	19.4	31.3	41.5
	1994-98	31.2	16.5	27.4	43.9
	1999	30.1	14.8	25.5	45.8
Retention	1989-93	1.7	-0.2	0.6	2.3
(mg P $m^{-2}d^{-1}$)	1994-98	0.4	-0.3	0.5	1.8
	1999	2.3	-0.2	0.6	1.5
Retention (%)	1989-93	7.7	-5.4	7.6	16.6
	1994-98	9.1	-4.1	14.9	23.7
	1999	12.0	-5.9	8.1	23.9

4.2.3 Water chemical conditions, status and trends

Phosphorus and nitrogen

In 1999, the annual mean concentration of total phosphorus (TP) was 0.11 mg P l^{-1}, which is almost a 50% reduction compared to the 1989 mean of 0.20 mg l^{-1}. The decrease was most significant in the most nutrient-rich and most strongly sewage-polluted lakes. In 19 of the 27 freshwater monitoring lakes, a significant reduction has now been recorded, the concentration having increased in one lake only (figure 4.5).

During the period 1989-93 to 1999 the annual mean total nitrogen (TN) concentration was reduced by approximately 20% to 2.3 mg l^{-1} in 1999. The most dramatic decrease is found in lakes with the highest concentrations. In 7 of the 27 lakes, the reduction is significant. The median value has declined from 2.1 to 1.5 mg N l^{-1} during the period. Summer average concentration has also declined approx. 20%.

The reduction in nutrient salt concentrations is a consequence of the overall reduced input concentrations (table 3.3). The reduction is most pronounced for nitrogen, as the phosphorus release from the sediment to the water phase to some extent corresponds to the reduction in inlet concentrations.

Brackish lakes

In all brackish lakes, nutrient concentrations were high; TP concentrations thus being above 0.1 mg P l^{-1} and TN between 1 and 4 mg N l^{-1}. The investigation of the 4 brackish lakes is a new element of the monitoring programme, and conclusive data are thus not available yet.

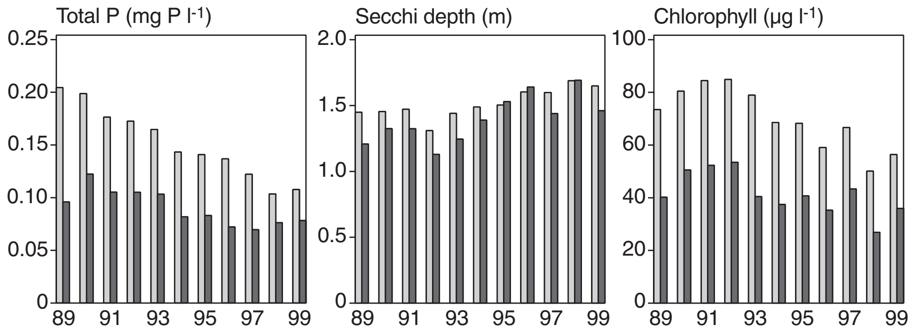

Figure 4.5 Development in average (light grey) and median values (dark grey) in 27 freshwater monitoring lakes, 1989-1999. A: Lake water total phosphorus (mg P/l), annual values. B: Secchi depth (m), summer values. C: Chlorophyll (µg l^{-1}), summer values. Source: *Jensen et al. (2000)*.

Chlorophyll a *and Secchi depth*

The depth to which light will penetrate into a waterbody depends on the absorption by the water itself and absorption by suspended particles. Secchi depth is the depth of penetration at which approx. 10% of the surface light is left. The water's content of chlorophyll rises with increasing phytoplankton abundance, which leads to reduced light penetration and thus reduced Secchi depth.

During the period 1989-1999, Secchi depth increased by ca. 25 cm to 1.9 m, especially owing to an increase in the Secchi depth in the most transparent lakes. Correspondingly, an almost 50% reduction occurred in chlorophyll *a* for this group. A reduced chlorophyll *a* level in the most turbid lakes is not reflected by a corresponding increase in Secchi depth. Median values are generally unchanged.

In summer, Secchi depth increased 20 cm in the 25% most turbid lakes. In the 25% most transparent lakes, an approx. 30 cm increase in Secchi depth corresponded to a decline in chlorophyll *a*. Also here, median Secchi depth values remained relative constant, whereas Secchi depth increased.

4.2.4 Biological structure

Phytoplankton

In 7 of the 27 lakes, a significant decrease occurred in phytoplankton biomass, whereas an increase was observed in only 3 lakes. Summer average total biomass declined from 15.2 $mm^3 l^{-1}$ in 1989-93 to 9.4 $mm^3 l^{-1}$ in 1999, while the summer median did not decline markedly.

The relative composition of phytoplankton changed in several lakes, i.a. the percentage of cyanophytes increased in 4 lakes, but declined in 8 lakes. The abundance of the clearwater species, chrysophytes, increased markedly in several lakes. Also the mean biomass of dinoflagellates increased significantly during the period 1989-93 to 1999.

Table 4.3 Environmental state in 1999 in the monitoring lakes illustrated by key parameters shown as mean summer values. Source: *Jensen et al. (2000)*.

Parameter	n	Mean	25 %	Median	75 %
Phytoplankton ($mm^3 l^{-1}$)	27	9.4	3.0	8.4	14.4
Cyanobacteria (%)	27	20.5	1.1	11,3	35.2
Zooplankton (mg dw l^{-1})	27	0.73	0.35	0.45	1.07
Zooplankton grazing (% d^{-1})	27	30.3	14.4	26.7	36.0

Zooplankton

Mean total biomass of zooplankton decreased by 0.10 mg dry weight l^{-1}, and the median value of zooplankton biomass declined from 0.69 to 0.45 mg dry weight l^{-1} during the period 1989-93 to 1999. The abundance of small cladocerans and rotifers declined, and especially the maximum abundance of calanoid copepods, small and large-sized cladocerans and *Daphnia* decreased. In contrast, the average biomass of *Daphnia* increased, especially due to an increase in the 25% of the lakes with the highest abundances.

In brackish lakes, zooplankton biomass is completely dominated by calanoid copepods and rotifers, whereas cladoceran abundance is low.

In the monitoring lakes, the average number of rotifers ranges between 1,600 and 3,500 indiv. l^{-1} in summer, corresponding to 70-80% of the total number of zooplankton, while they typically constitute around 5 and 15% of the total zooplankton biomass in each individual lake during summer.

The grazing capacity of zooplankton

Generally, it seems as if the capacity of zooplankton to graze down phytoplankton has increased in the monitoring lakes. This removal of phytoplankton contributed to the improvement of Secchi depth. Calculations show that both summer values for average and, especially, median grazing pressure have increased during the period 1989-93 to 1999, the latter from 19.1 to 26.7% d^{-1} owing to an increase in the 25% of the lakes with the lowest grazing pressure.

Submerged macrophytes

In general, the abundance of submerged macrophytes increased during the period 1989-1998, although a marked reduction occurred in 1999 in 6 of the 14 lakes in which sampling was made (figure 4.6). Median coverage was thus only 5% in 1999 compared to 21% in 1993-1998. The changes in depth distribution were not as pronounced. The reasons for the decrease are ambiguous, but may partly be ascribed to impoverished light conditions for the already established macrophyte assemblages due to reduced Secchi depth. In some lakes the increasing water level may have been a contributory factor.

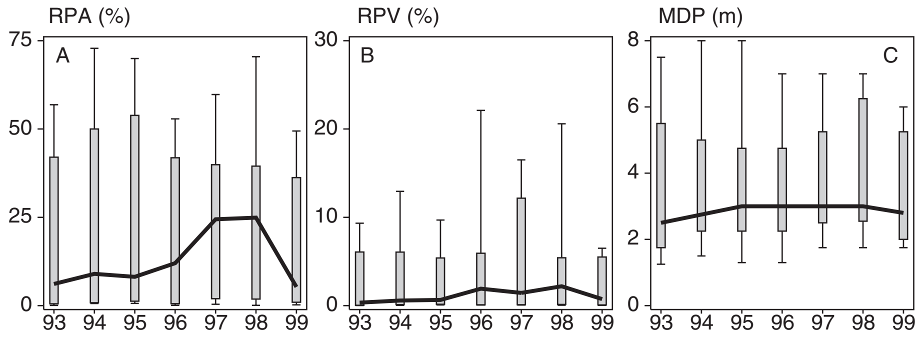

Figure 4.6 The development in abundance of submerged macrophytes in the 14 lakes, 1993-99. A: Relative plant-covered area (RPA, %). B: Relative plant-filled volume (RPV, %). C: Maximum depth distribution (MDP, m). Source: *Jensen et al. (2000).*

Fish fry investigations

Investigations show that perch and roach are by far the most common species, relative to both weight and number. They were found in nearly all monitoring lakes, and also ruffe was found in about 1/3 of the lakes. Compared to 1998, the number of young-of-the year (YOY) perch was higher, both in absolute numbers and compared to young-of-the-year roach.

The length distribution of the fish fry indicates that the breeding success of perch was generally higher in 1999 than in 1998, the opposite prevailing for roach. This corresponds with the fact that temperatures were high in the early summer of 1999, favouring the early-spawning perch.

As YOY roach, YOY perch are planktivorous, but contrary to roach, perch become piscivorous when reaching a certain size. If conditions are favourable, and the breeding success of perch results in high abundance of predatory perch, these may potentially contribute to the regulation of the planktivorous roach. This will lead to higher abundance of zooplankton and hence a high grazing pressure of zooplankton on phytoplankton.

4.2.5 Reactions to decreasing phosphorus concentrations

Freshwater lakes

When analyzing the development up till now, a pattern can be traced in the response of the lakes to reduced phosphorus concentrations. In the most nutrient-rich lakes, there is an immediate decline in phytoplankton abundance due to the reduced nutrient concentrations. Also in the less nutrient-rich lakes there is a decrease in phytoplankton abundance, which can be ascribed to both reduced nutrient concentrations and increased grazing. The latter is conditioned by changes in the fish stock composition towards higher abundance of predatory fish and lower abundance of planktivorous fish.

Brackish lakes

In brackish lakes, phytoplankton abundance is solely regulated by nutrient levels; fish and crustaceans prey so heavily upon the zooplankton that it becomes incapable of regulating the density of phytoplankton. The biomass of zooplankton in brackish lakes is lower than at corresponding phosphorus concentrations in freshwater lakes.

4.2.6 Environmental state and objectives

Trend

Overall, the environmental state of the monitoring lakes has improved from 1989 to 1999, especially owing to the reductions in phosphorus inputs due to improved sewage treatment, cf. chapter 3. Improvements have especially been registered for the physico-chemical parameters (i.a. Secchi depth and phosphorus concentrations), but also in biological structure (especially phytoplankton).

No improvement in quality objective compliance

Despite the improvements, the majority of the 31 lakes do not meet the quality objectives elaborated by the counties. Thus, the objectives were met in only 7 of the lakes in 1999. To obtain improvements in the environmental state in lakes failing to meet their quality objective, further reductions of phosphorus inputs are required.

4.3 Watercourses and springbrooks

4.3.1 Characteristics of Danish watercourses

The combined length of Danish watercourses is approx. 64,000 km. During the past 100 years, the watercourses have undergone several major changes. In many places, water abstraction has resulted in reduced water flow. Watercourses have been culverted, straightened, deepened and widened to improve the cultivation of the adjacent catchments. Moreover, watercourses are kept in an artificial state by weed clearance and removal of sand and mud accumulations. In addition, many watercourses are impacted by wastewater from sewage treatment plants, fish farms, dwellings located outside drained catchments, and stormwater overflows from the sewerage systems in the event of heavy rainfall.

Table 4.4 The approximate length of Danish watercourses. Source: *Windolf et al. (1997).*

Width, m	Length, km
>0-2,5	48,000
2.5-8.0	14,500
>8.0	1,500
In total	64,000

Monitoring stations

The majority of Danish watercourses are less than 2.5 m wide (table 4.4). The watercourses included in the NOVA monitoring programme have been selected so as to represent all Danish watercourses, both as to size and general environmental state.

Water chemical investigations are performed at 231 monitoring stations in watercourses and 58 stations in springbrooks, and biological investigations are performed at 1,053 stations. The stations represent 6 catchment types, comprising natural catchments, two types of agricultural catchments, built-up catchments, as well as point source and fish farm impacted watercourses.

4.3.2 Concentrations of phosphorus and nitrogen: status and trend

Nitrogen

As in previous years, the total nitrogen concentration in 1999 was highest in watercourses draining cultivated catchments. In these, the concentration is 4.5 times higher than in watercourses located in natural catchments (table 4.5).

Table 4.5 Mean annual concentrations, area coefficient and discharge-weighted concentrations of nitrogen from the different catchment types in 1999. Source: *Bøgestrand (ed.) (2000)*.

Nitrogen 1999		Natural catchments	Agricultural catchments	Point-source catchments
Number of stations		9	92	78
Annual mean concentration				
Total N	mg N l^{-1}	1.24	5.82	4.95
NO_3-N	mg N l^{-1}	0.74	5.00	4.13
NH_4-N	mg N l^{-1}	0.03	0.12	0.16
Discharge-weighted concentration				
Total N	mg N l^{-1}	1.49	6.90	5.81
NO_3-N	mg N l^{-1}	0.96	6.01	5.04
NH_4-N	mg N l^{-1}	0.03	0.13	0.17
Runoff mm		236	359	402
Catchment size km^2		5.04	44.0	217

Trend

In most Danish watercourses, the nitrogen concentration has declined since 1989, taking into account variations in discharge. Thus a decline was calculated in 139 of 165 watercourses (figure 4.7 a). The decline, which typically amounts to 16% (median), was statistically significant for 60 watercourses. Most significant and definite is the decline in watercourses formerly loaded by sewage, but a tendency to a slight reduction in nitrogen transport in watercourses draining agricultural catchments without significant sewage inputs was also observed. In these watercourses, a reduction of approx. 13% (median) was recorded, the decline being significant in only 27% of these, however.

Agricultural monitoring catchments

In two watercourses situated in the agricultural monitoring catchments, a statistically significant increase ($p<0.05$) in nitrogen loss has been recorded since 1989. In the watercourses located in the other three catchments, no significant development was observed. In the test, corrections are made for changes in discharge, but not for changes in the soil nitrogen pool due to shifts between wet and dry years.

Springbrooks

In springbrooks situated in agricultural catchments, the nitrate concentration has increased slightly since 1989, but with a trend towards declining concentrations in the latter part of the 1990s. In many of the springbrooks with high nitrate concentrations, significant increases have, however, still been recorded.

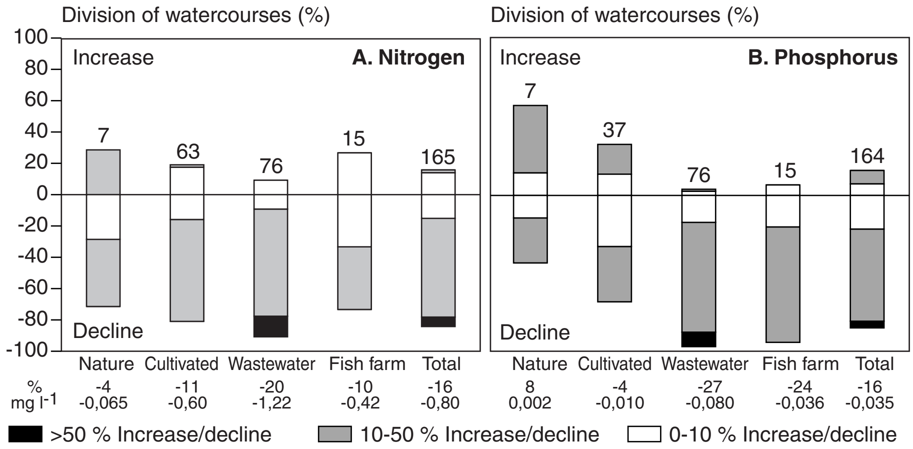

Figure 4.7 Per cent changes in concentrations from 1989-1999 in all watercourses on which at least a 9-year data series for 4 catchment types are available. A: Total nitrogen. B: Total phosphorus. The watercourses have been subdivided according to the size of change. Watercourses with increases and declines in concentrations are shown, respectively, above and below the zero line. Below the figure, the change for each catchment is given as a median value in per cent and as concentration. Above the columns the number of stations within each category is shown. Source: *Bøgestrand (ed.) (2000).*

Phosphorus

The total phosphorus concentration in 1999 was, as in earlier years, highest in watercourses located in catchments exhibiting point sources and fish farms, followed by agricultural catchments. Within these, concentrations are 2-3 times higher than in watercourses situated in natural catchments.

Table 4.6 Mean annual concentrations, area coefficient and discharge-weighted phosphorus concentrations from different catchment types in 1999. Source: *Bøgestrand (ed.) (2000)*.

Phosphorus 1999		Natural catchments	Agricultural catchments	Point source catchments
Number of stations		9	62	78
Annual mean concentrations				
Total P	mg P l^{-1}	0.056	0.150	0.178
PO_4-P	mg P l^{-1}	0.024	0.069	0.092
Discharge-weighted concentrations				
Total P	mg P l^{-1}	0.055	0.143	0.165
PO_4-P	mg P l^{-1}	0.023	0.058	0.076
Discharge mm		236.2	354.5	402.2
Catchment size km^2		5.04	15.32	217.5

Trend

A marked reduction in the phosphorus concentration has occurred up till 1999 in watercourses that in 1989-91 were influenced by inputs from sewerage treatment plants and fish farms (figure 4.7 b). On average, a 27% decline was recorded. In most watercourses draining agricultural catchments without significant point sources, there has also been a tendency to slightly declining phosphorus concentrations since 1989, but the tendency is only significant for a limited number of watercourses. The reduction can be explained by reduced outlet of phosphorus from scattered dwellings owing to the increased use of phosphorus-free detergents.

Watercourses with increasing phosphorus concentrations typically drain sandy and sandy-clayey catchments and seem to concentrate in i.a. northern Jutland. Only for very few of these watercourses can significantly increasing concentrations be established.

Springbrooks

In 1999, the median concentration of phosphorus in springbrooks and springs in natural catchments was 0,034 mg P l^{-1} compared to 0,056 mg P l^{-1} in agricultural catchments. There is a slight, although insignificant, decline in total phosphorus concentrations both in springbrooks with high and low phosphorus concentrations. Likewise, a slight, but insignificant, decrease in phosphate was recorded in phosphate in agricultural catchments, except for springbrooks with very high phosphate concentrations.

4.3.3 Environmental state of watercourses

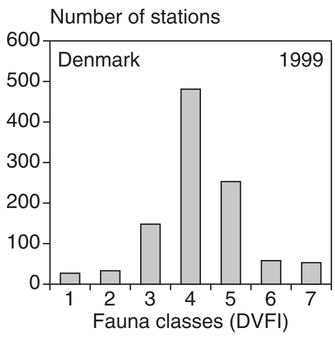

Figure 4.8. Biological stream quality (DVFI) in 1999 for 1053 monitoring stations in Denmark. Source: *Bøgestrand (ed.) (2000).*

To estimate water quality, investigations are made of the composition and abundance of fauna according to the Danish Stream Fauna Index. Seven fauna classes are defined: 1, 2 and 3 are assigned to watercourses that are heavily or severely polluted, fauna class 4 to moderately polluted watercourses, while fauna classes 5, 6 and 7 are assigned to unpolluted or only slightly polluted watercourses.

For 1999, the results show that the dominant state in Danish watercourses is fauna class 4, prevailing at 45% of the stations (Figure 4.8). Here, either the majority or the most demanding species are absent or their abundance is very low. 34% of the stations were rated as fauna classes 5, 6 and 7, while the remaining 20% belonged to fauna classes 1, 2 and 3.

The environmental state of watercourses more than 5 m wide is generally better than that of more narrow watercourses. Fauna classes 1, 2 and 3 occurred at 22% of the stations in narrow watercourses compared to 8% in wide watercourse. Contrarily, fauna classes 5, 6 and 7 were represented in 33% of the narrow watercourses compared to 44% in wide watercourses.

Differences between eastern and western Denmark

For Denmark as a whole, a significant relationship can be evidenced between fauna class and sediment characteristics of watercourses. The environmental state is, however, significantly better in Jutland and on Funen than in the remainder of the country. On Funen and in Jutland, fauna classes 5, 6 and 7 are found at, in total, 42% of the stations, while fauna classes 1, 2 are found at 13% of the stations. The corresponding values for Zealand, Lolland and Falster, are 15% and 38%, respectively. The difference cannot be explained by differences in streambed characteristics. However, watercourses are smaller and specific runoff lower east of the Great Belt, so losses from scattered dwellings and stormwater outfalls are consequently less diluted here. The data available for estimation of the impact of oxygen-demanding substances, BI_5, are inadequate for estimating the impacts hereof.

The possibility exists that the fauna present east of the Great Belt may spread to formerly polluted localities and thus essentially improve the present state of the biological quality of the watercourses.

Quality objective compliance

In 1999, the quality objectives for water quality have only been met at 39% of the monitoring stations, with the highest objective compliance (76%) being recorded at the stations for which severe objectives have been stipulated by the counties. Objective compliance is 37% for monitoring stations in watercourses less than 5 m wide and 46% for larger watercourses.

4.4 Marine waters

4.4.1 Hydrographic conditions

A significant hydrological incident in 1999 forced oxygen-depleted and nutrient-rich water from the Belt Sea so far into the eastern Jutland fjords that it came to form the surface layer.

In the inner marine waters, stratification was stronger than normal due to the calm weather, cf. section 2.1. Renewal of the bottom water in the Belt Sea and the Kattegat was therefore reduced and the retention time prolonged. Moreover, there was a steady outflow of water from the Baltic Sea during most of the year. Despite the warm summer in 1999, the bottom water was colder than normal probably because the inflow from the Skagerrak occurred earlier than normal and in consequence was colder than normal.

Relative to the normal, stratification in coastal waters and in threshold fjords was more pronounced than usual due to higher influx of heat to the surface water and colder bottom water.

4.4.2 Oxygen conditions

Oxygen deficiency in 1999

Due to the marked stratification of the water column in 1999, the export of oxygen to the bottom water declined. Severe oxygen deficiency developed (below 2 mg l^{-1}) in the Belt Sea and in the Arkona Sea. In coastal areas, widespread oxygen deficiency developed in the waters around Funen, in the Limfjorden, and in several fjords in southern and eastern Jutland (figure 4.9).

Generally, oxygen deficiency was triggered by climatic and hydrographic conditions. Also, incidents of oxygen deficiency were attributable to high oxygen consumption at the seafloor and in the bottom water, indications of enhanced eutrophication in the areas. In some cases, oxygen deficiency was so severe that part of the bottom fauna disappeared.

Trend

From the mid-1970s until the beginning of the 1990s, a significant reduction in oxygen concentrations has occurred in the Kattegat, the Sound, the Great Belt and the southern Belt Sea. During the period 1989-99, a significant increase in minimum oxygen concentrations has been observed in spring in the Great Belt and the Femern Belt, but no general trend in autumn oxygen concentrations can be traced. In coastal areas, no clear trend in oxygen conditions can be observed.

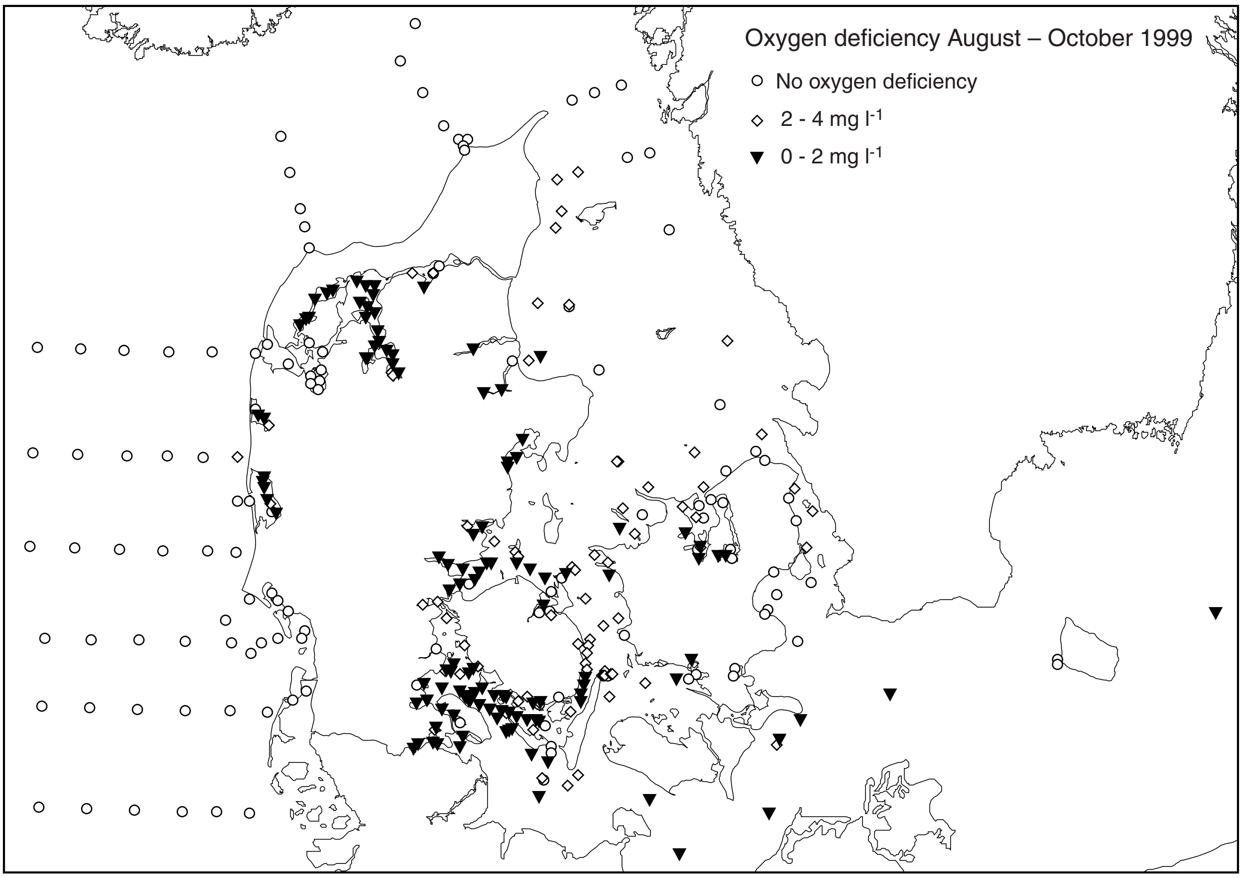

Figure 4.9 Stations in Danish waters where oxygen was measured and where oxygen deficiency (< 4 mg l^{-1}) or severe oxygen deficiency (< 2 mg l^{-1}) was observed at least once during the months of August-October.

4.4.3 Nutrient concentrations, status and trends

Phosphorus

The concentration of phosphate in estuarine fjords and coastal areas is closely related to the level of nutrient inputs from the land. In 1999, the phosphate concentration in all fjords and at coastal stations was 10.4 µg l^{-1} and thus unchanged from 1998, and the anticipated high level in consequence of high freshwater runoff did not appear, cf. section 3.5.2.

The annual mean concentration of total phosphorus in estuarine fjords and coastal areas was 38 µg l^{-1} in 1999. Seen over a longer-term time period, the marked reduction in total phosphorus and phosphate from levels of around, respectively, 65-70 and 25-30 µg l^{-1} in the beginning of the monitoring period seems to have gradually stabilized around 25-40 and 10-12 µg l^{-1}, respectively, in fjords and coastal waters.

In the open marine waters, the annual mean concentration of phosphate in 1999 was 3.5 µg l^{-1}, which is significantly lower than the levels in the beginning of the 1990s of 10-11 µg l^{-1}. The total phosphorus concentration was 30-32 µg l^{-1} in 1999 compared to 18.3 µg l^{-1} in 1989-1990.

Nitrogen

In estuarine fjords and coastal waters, the concentration of inorganic nitrogen is closely correlated with both inputs from the land and with nitrogen loading. The concentration of inorganic nitrogen in 1999 was 120 µg l^{-1} and did, as in 1998, not quite reach the levels to be expected from the runoff values. Only Limfjorden shows a significant decline in inorganic nitrogen during the period 1989-99. The total nitrogen concentration in 1999 was 648 µg l^{-1}.

In open marine waters, the mean concentration of inorganic nitrogen in 1999 was 13 µg l^{-1} and thus higher than in the previous years. Mean total nitrogen was 298 µg l^{-1}. In contrast, neither the inorganic nitrogen nor the total nitrogen concentrations have changed substantially during the period 1974-99.

4.4.4 Phytoplankton

Nutrient limitation

The concentrations of nutrients in the fjords resulted in days with nutrient-limited growth, varying from 40 to approx. 200 days in 1999. The number of days with nutrient-limited growth varied greatly between the fjords, as did the limiting factor. However, phosphorus was the limiting factor for a few more days than nitrogen. The pattern corresponds to that of earlier years.

Nitrogen was the most important potential limiting nutrient in the open marine waters in 1999. The period with potential nutrient limitation was highest in the Baltic Sea and in the Kattegat with 8 months, while it was 6 months in the Sound and the Belt Sea. This pattern corresponds to what has been seen in recent years.

Phytoplankton abundance in 1999

The climatic conditions favoured phytoplankton growth. The high level of precipitation meant that nutrient supply was high, enhancing the potential for high phytoplankton biomass. Especially in late summer and during autumn, algal blooms developed in a number of eastern Jutland fjords.

In 1999, phytoplankton biomass measured as chlorophyll was generally somewhat higher than in previous years in open marine waters, while in coastal waters the levels were of the same magnitude as in the preceding years. In coastal and marine open waters, the annual mean chlorophyll concentrations were 4 and 2.2. µg l^{-1}, respectively. As for chlorophyll in the fjords, the annual variations are positively correlated with the concentrations of phosphorus and nitrogen and with the influx of light. During the period 1989-99, a slight but insignificant decrease in the chlorophyll level of coastal waters has occurred. In contrast, primary production, a measure for phytoplankton growth, has declined significantly.

Trend

In open marine waters, no clear trend in chlorophyll levels can be detected during the past 10-30 years. The inter-annual variations can partly be ascribed to nitrogen loading, whereas no correlation with phosphorus can be determined. This corresponds with the fact that phytoplankton growth is primarily limited by nitrogen. Here there is no evident relationship between chlorophyll and the influx of light, which owes to the circumstance that biomass, due to nutrient limitation, is essentially lower and is not the cause of self-shading.
Direct countings of phytoplankton biomass show a declining trend for phytoplankton in open waters during the past 10 years.

Species composition

The composition of phytoplankton did not differ significantly from that of the preceding years. Most noteworthy were the great autumn assemblages of diatoms belonging to the genus *Pseudo-nitzchia*. Relative to the end of the 1980s, the abundance of dinoflagellates has increased, whereas nanoflagellates have become more rare. Such a change in phytoplankton species composition may be greatly important for the turnover of phytoplankton in the marine ecosystem, including the extent of the share sedimenting to the bottom.

Algal blooms

The most characteristic blooms in 1999 were those of the diatom *Skeletonema costatum* and species of *Pseudo-nitzchia,* and the dinoflagellates *Prorocentrum minimum* and *Gymnodinium chlorophorum*.

Toxic algae

No data exist on the species composition of the phytoplankton in the Baltic Sea in 1999. At all remaining marine stations, potentially toxic algae were found, but no toxic effects on other organisms were recorded.

At the western coast of the island, Fanø, bathing was prohibited for approximately one week in July due to blooms of *Noctiluca* and *Phaeocystis*, and at the south-western coast a trend towards decreasing abundance of benthic invertebrates was observed, especially among cockles and lugworms. In the Little Belt, *Dinophysis* was found in concentrations exceeding the limit values for mussel fishing.

4.4.5 Submerged macrophytes vegetation

No clear trend in the abundance of macroalgae and eelgrass during the monitoring period 1989-99 can be detected, neither in the inner or outer estuarine areas nor along the open coasts (figure 4.10).

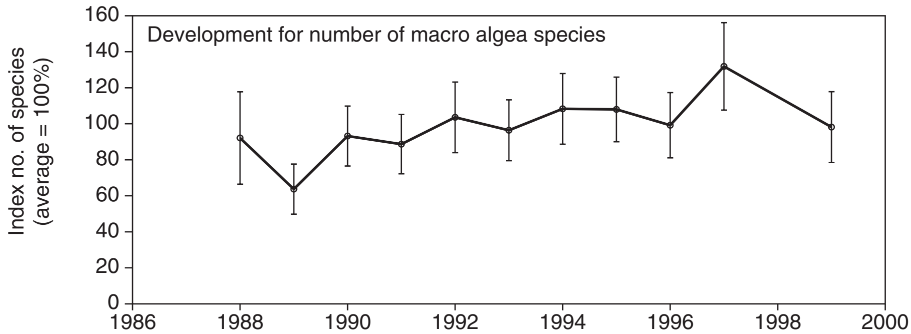

Figure 4.10 Index showing species number of macroalgae 1989-1999. The species number of each depth interval in each fjord/coastal area has been indexed according to the species number recorded in the area in 1999. The analysis includes only areas on which data for a period of at least 5 years are available. The figure shows an average index for 28 fjords/coastal areas. Standard error = SE. Source: *Hansen et al. (2000).*

Reduced species number and depth distribution

The depth distribution for eelgrass and the number of macroalgae species decreased in 1999. In contrast, the coverage of eelgrass increased, and the declining trend in the abundance of eutrophication-dependent macroalgae observed since 1989 continued. The decline in the depth distribution of eelgrass corresponds with the reduced light influx to the water column in 1999 in comparison with the preceding 3 years due to higher water supply/nutrient inputs from the land. Thus, whereas light conditions were poorer in deep water, the many hours of sunshine in 1999 have probably led to improved light conditions in shallow waters, which may explain the greater coverage of eelgrass here.

On the reefs in open marine waters, a similar effect of lower Secchi depth in the form of poor depth distribution of macroalgae was observed. In 1999, the depth distribution in the Kattegat was thus the poorest since 1990.

Dominance

The relationship between eutrophication-dependent and non eutrophication-dependent macroalgae showed a weak trend towards increasing abundance of non eutrophic-dependent macroalgae, meaning that the abundance of eutrophication-dependent algae fell in 1999. The coverage of one-year macroalgal species has shown a decreasing trend for a number of years, a positive development indicating reduced eutrophication.

The variations in vegetation conditions in 1998 and 1999 compared to 1996 and 1997 can be significantly related to both nutrient inputs hampering and light influx favouring the vegetation. However, sea urchins occurring in excessively high abundances constitute an essential limiting factor for macroalgae in the deeper parts of a few reefs located in the southern Kattegat and the Belt Sea.

4.4.6 Benthic fauna

Biomass and number of individuals

In the inner open Danish marine waters, there was a significant increase in the number of individuals and biomass, from, respectively, 1500 individuals m^{-2} and 168 g wet weight m^{-2} in 1998 to 1800 individuals m^{-2} and 332 g wet weight m^{-2} in 1999. The reason is probably improved access to food for the benthic fauna. The level is, however, still lower than in 1995 when the number of individuals was as high as 4869 per m^2.

Species composition

No marked changes in the composition of the benthic fauna occurred in 1999. The last major shift in species composition occurred during the transition between the 1980s and 1990s when crustacean abundance declined and that of bristle worms increased, and the 1999 composition mirrored that of the preceding years of the 1990s.

There is a positive correlation between number and biomass of benthic fauna and nutrient inputs to the open marine areas, with a delay, however, of 2 years. Especially the species with the shortest mean life expectancy (primarily bristle worms and crustaceans) exhibit the strongest positive correlation with the degree of eutrophication.

In coastal areas there was a trend, although insignificant, towards an increase in the biomass of benthic fauna. The development between 1998 and 1999 was much less unambiguous in coastal areas than in open waters. There are great geographical differences between benthic faunal communities in the different coastal areas compared to the conditions in the Kattegat area, where the fauna is more uniform.

This is due to the fact that coastal areas are more diverse as to physico-chemical conditions than are stations in the open sea.

The general effect of the incidents of oxygen deficiency in 1999 on the benthic fauna is unknown, as the gathering of benthic faunal samples was undertaken before the incidents became extensive. Possible effects may be detected in 2001.

4.4.7 Overall trends in the environmental state of marine waters

The climatic conditions in 1999 had a series of negative effects on the marine environment, and the improvement initiated in 1996 was somewhat weakened in 1999. When the complete monitoring period 1989-1999 is considered, however, an improvement has occurred. The most marked change in the state of eutrophication is the decline in the concentration of phosphate, which has now stabilized. Especially improved wastewater treatment has resulted in decreased outputs of phosphorus from the land.

In coastal areas, phytoplankton production has declined, but the occurrence of incidents of algal blooms and oxygen deficiency show that the general level of eutrophication is still high.

None of the monitoring stations met the quality objectives stipulated by the counties in 1999. At the present levels of input of especially nitrogen and phosphorus, significant changes in the state of the marine environment are not to be expected in the near future. To obtain further improvements of the marine environment, the inputs of nutrients must be further reduced.

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5 Heavy metals and hazardous substances

Monitoring of heavy metals and hazardous substances was included to a varying degree in the various parts of the NOVA programme in 1999.

Table 5.1 List showing the area in which heavy metals and hazardous substances were monitored in 1999.

	Point sources		Atmos-phere	Sea-water	Mussels	Fish	Water-courses	Ground-water
	Waste-water	Sludge						
Heavy metals	x	x	x		x	x	x	x
Inorganic trace elements								x
PCB and chlorinated pesticides	x	x			x	x		
Dioxines and furans		x						
Organotin compounds					x			
PAH		x			x			
Aromatic hydro-carbon								x
Ethere (MTB)								x
Chlorinated hydro carbon				x				x
Pentachlorophenol (PCP)				x				x
Phenol and nonylphenols		x						x
Softeners		x						x
Anionic detegents								x
LAS				x				
Aliphatic amines								
Pesticides								x

Pesticides in groundwater and heavy metals in the atmosphere have been monitored for a sufficient number of years to make it possible to assess the developmental trends. Similarly, the level of heavy metals in fish has been monitored since 1978. Monitoring of heavy metals and hazardous substances in other parts of the monitoring programme has only been performed for a limited number of years and it is therefore only possible to assess the geographic distribution of these substances.

5.1 Heavy metals and inorganic trace elements

Heavy metals exist naturally in the environment. Due to human activity the metals are, however, allowed to spread and the metals furthermore leach to soil and surface water via the atmosphere and point sources.

5.1.1 Point sources

Wastewater

The concentration of heavy metals in wastewater was studied at 19 selected wastewater treatment plants, corresponding to about 25% of the total amount of wastewater in Denmark. The concentration of heavy metals is of the same magnitude as was found in studies in 1994 and 1996 and at the same or a lower level than that found in 1998.

Water quality objectives

If the heavy metal concentrations are compared with the quality objectives for the aquatic environment, the discharge concentrations are generally lower than the specified quality objectives (table 5.2).

Wastewater sludge

The concentration of heavy metals in wastewater sludge is estimated on the basis of measurements at 19 selected wasterwater treatment plants. When comparing these results with those of a study from 1997, it is revealed that the concentration is at a similar level, except for cadmium and lead where the values are somewhat higher than in 1997.

5.1.2 The atmosphere

The concentration of heavy metals in the atmospheric deposition includes the content in precipitation and the particles that are deposited during dry periods.

A similar trend is found for metal concentrations at seven monitoring stations where deposition of heavy metals is monitored. The monitoring stations are placed in rural districts in various locations in Denmark with no ”dusty” activities in the vicinity. The highest concentrations of all metals are found at the station situated closest to Copenhagen.

Reduction in metal concentrations in the atmosphere

There has been a steady reduction in the concentrations of heavy metals in the atmosphere for the period 1989 to 1999. The content of lead has been reduced by a factor 4, mainly due to the use of lead-free petrol in Denmark and the countries surrounding Denmark. There has also been a marked reduction in the level of chromium and arsenic as a result of improved cleaning of exhaust from coal-powered plants, the close-down of small and inefficient plants as well as the increased use of natural gas.

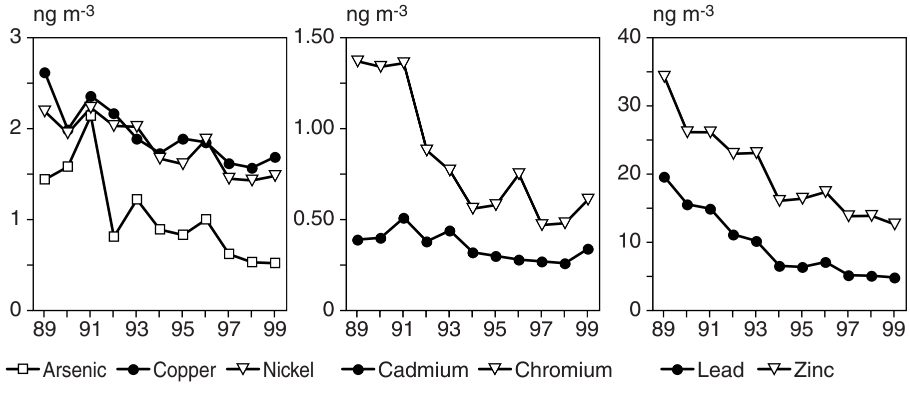

Figure 5.1 Annual average of mean concentrations measured at various background stations during the period 1989 – 1999 *Hovmand og Kemp (2000)* (modified).

5.1.3 Mussels and fish

In the majority of the studied areas, mussles and fish have been found to contain relatively low concentrations of heavy metals. These concentrations do not raise concern in relation to the relevant reference and background concentrations. In localized areas in some of the internal inlets, increased concentrations of mercury, cadmium, zinc and copper have been detected, indicating the presence of local point sources. The metals have been found in mussels in concentrations listed according to increasing concentration level: mercury and lead (identical level), cadmium, nickel, copper and zinc.

Mussels

In the area around the Sound, relatively high concentrations of most heavy metals are found in mussels, although not markedly higher than in the other areas. The individual heavy metals are also found in correspondingly high concentrations in one or more different areas.

Fish

The concentration of heavy metals in fish is generally higher in the Sound than in the Great Belt and at Hvide Sande. The level of mercury concentrations in flounder in the Sound has been decreasing since the 1970s, while the cadmium level has been increasing since 1993. There is no explanation for the increasing cadmium concentrations, but Swedish investigations show a similar trend. (*Naturvårdsverket)*.

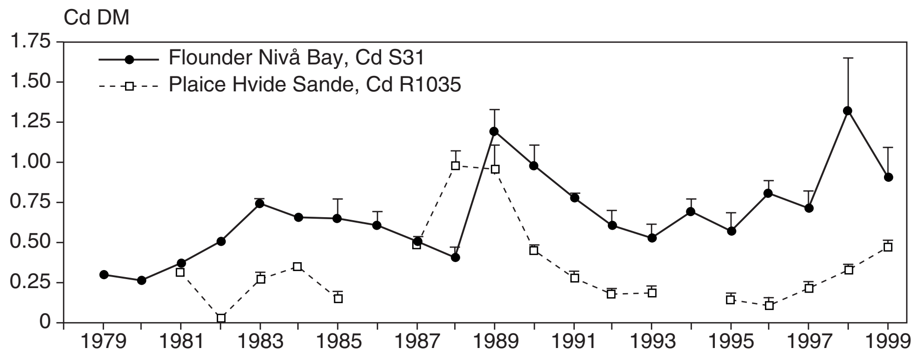

Figure 5.2 The annual variation in cadmium concentrations found in the liver of fish from the Sound (flounder) and Hvide Sande (plaice) (DM = dry matter). Source: *Hansen et al (2000)*.

5.1.4 Watercourses

Monitoring of heavy metals in watercourses includes the heavy metals, arsenic, cadmium, chrome, copper, mercury, lead, nickel and zinc.

Heavy metals have been found in watercourses in the following order, listed according to increasing concentrations: mercury, cadmium, lead, arsenic, nickel, copper and zinc. If the metal concentrations dissolved in water are considered on their own, the concentrations of arsenic, copper and nickel are the highest.

Lead, copper and zinc

The highest heavy metal concentrations are generally found in the rivers Gudenåen and Damhusåen. The concentrations of lead, copper and zinc in the Gudenåen are frequently higher than the water quality objectives, and the level of lead concentrations in the Damhusåen is also occasionally higher than the water quality objectives set (table 5.2).

Particulate heavy metals

The highest concentrations of particulate heavy metals are found in the river Damhusåen with the exeption of chrome, where the highest particulate concentrations are found in the river Odense Å. Out of the particulate metals, arsenic and zinc seem to have the largest potential impact on the environment.

Table 5.2 Heavy metals in watercourses and discharge from wastewater treatment plants compared with the Danish quality objectives. Source: *Bøgestrand (ed.) (2000) and Danish EPA (2000c).*

Unit: µg l^{-1}	Watercourses (Interval for maximum value in 4 streams)	Discharge from wastewater treatment plants average +/- variation	Water quality objectives[1)] Denmark
Arsenic	1,1-2,4	1,2 +/- 0,7	4
Cadmium	0,04-0,14	0,2 +/- 0,3	5
Chrome	1,6-3,1	1,8 +/- 1,3	10
Copper	2,9-49	7,2 +/- 8,7	12
Mercury	0,005-0,021	0,2 +/- 0,1	1
Lead	1,2-75	2,6 +/- 2,4	3,2
Nickel	3,0-31	8,2 +/- 7,5	160
Zink	14-486	105 +/- 114	110

1) Statutory order No. 921 of 8 October 1996 regarding quality objectives for wetlands and requirements of discharge of certain hazardous substances to watercourses, lakes or the sea

5.1.5 Groundwater

A number of heavy metals and inorganic trace elements are inlcuded in the monitoring of groundwater. Nickel is included in the waterworks control of the water quality of the abstraction wells, whereas the other heavy metals and inorganic trace elements are only included to a limited extent. Some heavy metals are also included in the monitoring of the upper groundwater encompassed by the agricultural monitoring programme.

Results of the the agricultural catchments monitoring programme reveal that the concentrations of heavy metals and trace elements are generally higher in the upper groundwater.

Nickel and zinc

The monitoring of groundwater evidences that nickel and zinc have been found in concentrations exceeding the limit value of 20 and 100 µg l^{-1}, respectively, in 5% of the monitored filters. The waterworks routine well control revealed corresponding figures of 3% and 7%. Both substances are thought to have been released from sediments as a result of a lowered groundwater table.

Aluminium

Aluminium has been found in concentrations exceeding the limit value for drinking water of 200 µg l^{-1} in 9% of the monitored filters, and in 22% of the wells monitored by the waterworks. This is mainly ascribed to low pH in the western part of Jutland. Some of the high values are, however, probably a result of a release of sediment containing bentonite.

Cadmium and selenium

Under the groundwater monitoring programme the substances cadmium and selenium have occasionally been found in concentrations exceeding the limit value for drinking-water.

Most of the inorganic trace elements in groundwater are assumed to be retained in the ochre sludge during the water treatment at the waterworks and are therefore not found in drinking water suppleded by the waterworks.*(Danish EPA (1999a)*.

5.2 Hazardous substances

5.2.1 Point sources

PCB in wastewater

Polychlorinated biphenyl (PCB) has been found in wastewater in concentrations exceeding the detection limit in isolated inlet samples, but not in discharge from wastewater treatment plants.

Sludge

Sludge from wastewater treatment plants has been analysed for dioxines and furans as well as PCB, PAH, alkylphenols and the softener DEHP. In 1999, the concentrations of the mentioned substances were found to be similar to those found in previous analyses of the occurrence of the substances in sludge.

Table 5.3 Concentration of the substances with cut-off values as stipulated in the the Danish Statutory Order on the use of sludge. Sludge may not be spread onto agricultural land unless the cut-off values are being observed. Source: *Danish EPA (2000c)*.

Unit: mg kg^{-1} TS	Average for all plants in 1999 [1)]	Average for plants from which sludge was spread onto agricultural land	Cut-off values[2)]
PAH	7.5	1.6	6 (3)
Nonylphenol (+ethoxylates) (NPE)	25	8,2	50 (30)
DEHP	25.7	22.3	100 (50)
LAS	2425		2600 (1300)

[1)] 17 selected wasterwater treatment plants, PAH, however, only 16 plants and LAS only 6 plants

[2)] Danish statutory order on sludge (Statutory Order No. 823 of 16 September 1996 on the use of waste products for agricultural purposes,) Values in brackets are applicable after 1 July 2000. Other values were applicable before 1 July 2000.

5.2.2 Seawater

Monitoring of hazardous substances in seawater includes chlorinated hydrocarbon, pentachlorphenol (PCP) and LAS. Chlorinated hydrocarbon and PCP were not detected in seawater at the two montoring stations in the inlets of Odense Fjord and Randers Fjord.

LAS

Very low concentrations of LAS were found in seawater in the inlet Randers fjord, while there was no detection of the substance in the Randers Fjord. LAS in these generally low concentrations is thought not to have a negative impact in the monitored areas.

5.2.3 Mussels, fish and snails

The aromatic chlorine compounds, PCB and chlorinated pesticides, are included in the monitoring of organisms, because these substances are still circulating in the environment although they are banned in Denmark and western Europe.

PCB i mussels

In most of the monitored areas, PCB has been found in concentrations exceeding the recommended eco-toxological evaluation criterion for PCB, indicating a possible impact of PCB on the environment (table 5.4).

Chlorinated pesticides in mussels

At most monitoring stations, chlorinated pesticides were found in mussels in lower concentrations in 1999 than in 1998. It is not evident if this is due to a reduction in the occurrence of these substances in the environment, or variations in the condition of the mussels (size and fat content) in 1998 and 1999.

Aromatic chlorine compounds in fish

The highest concentrations of organic aromatic chlorine compounds in fish are found in the Nivå Bugt and the lowst concentrations in the Great Belt and at Hvide Sande. The fish at Hvide Sande have the lowest fat content and because the substances concentrate in the fatty tissues, the level of organic aromatic chlorine compounds in relation to the fat content is higher in fish caught at Hvide Sande than in those from the Nivå Bugt.

PAH in mussels

The PAH concentrations in mussels are increased in a few areas in estuarine fjords with little water exchange and/or large point-source discharges. It is possible that the presence of some PAHs in these areas will have an impact on the ecosystem. In the other monitored areas, the PAH concentration is at a level corresponding to the concentration detected in waters with little pollution.

Tributyl tin (TBT) in mussels

Tributyl tin (TBT) was found at all stations in concentrations exceeding the recommended eco-toxological evaluation criterion for TBT (table 5.4). Therefore, detectable effects may be observed in all the monitored areas. The highest concentrations of tributyl tin (TBT) were found in mussels in an area characterized by heavy traffic of ships and other shipping related activities. Relatively high TBT concentrations in mussels have also been found in areas where water from treatment plants is being discharged.

TBT concentrations measured in 1999 were lower than those found in 1998 in most localities. Compared to the results of 1998, higher levels of the TBT metabolites dibutyl tin (DBT) and monobutyl tin (MBT) were detected. The reduced TBT level in 1999 may indicate that the effect of banning products containing TBT is starting to show. In 1999, TBT was, however, still found in mussels in higher concentrations than the metabolites, possibly indicating that mussels have been exposed to TBT until recently.

Table 5.4 Concentrations of selected hazardous substances in relation to recommended eco-toxological evaluation criteria. Source: *Hansen et al. (2000).*

	Concentration in mussels	EACs[1]
PCB	1.1 – 10.2 µg kg^{-1} wet weight	1 – 10 µg kg^{-1} wet weight
Anthracene		1 – 10 µg kg^{-1} wet weight
TBT-Sn	0.5 – 38 µg kg^{-1} wet weight	0.08 – 0.8 µg kg^{-1} wet weight

[1] The recommended eco-toxological evaluation criteria (EAC) of the OSLO-PARIS commission

Sea snails exhibit imposex characteristics

Due to the TBT impact, sea snails exhibit intersex characteristics, with the development of visible male genitalia in females.

Investigations of imposex in sea snails were performed on different snail species with various sensitivity towards TBT. Imposex in the most sensitive species (red whelk) appears in all the investigated localities where almost all the investigated red whelk in the inner open marine waters have developed imposex characteristics, while this trend was less apparent in the Skagerrak. Imposex in a less sensitive species (dogwhelk) appeared with a distinct gradient away from major port areas in the Horsens Fjord, Limfjorden near Aalborg, the Sound near Copenhagen and in Århus Bugt (figure 5.3). With a few exceptions, the results of imposex in 1999 are similar to the 1998 findings.

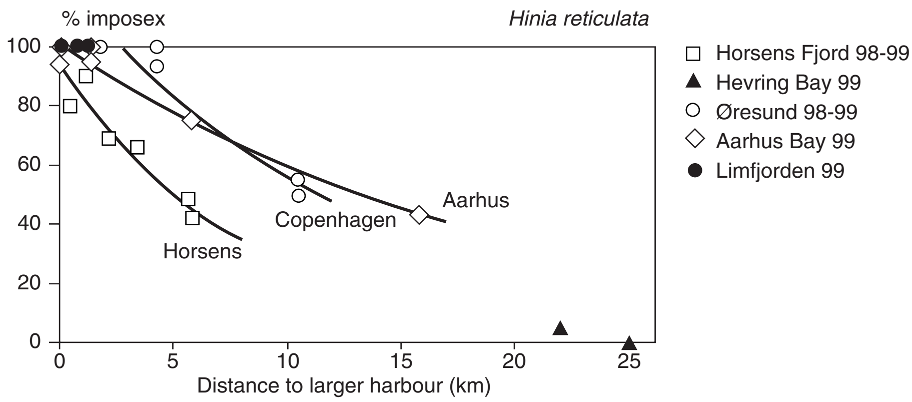

Figure 5.3 Relationship between imposex in dogwhelk (*Hinia reticulata*) and the distance to the nearest major harbours in various coastal areas. The occurrence of imposex is indicated as the percentage distribution of females with imposex. Hevring Bay is used as reference area. Source: *Hansen et al.* (2000)

5.2.4 Groundwater

In groundwater, a distinction is made between pesticides and other organic micro-pollutants. Pesticides and their metabolites are here referred to as an individual group among the organic micro-pollutants.

Groundwater has been analysed for organic micro-pollutants (except pesticides) since 1989, with an increasing number of annual analyses and a concurrent increasing number of analysed filters. There has been a concurrent increase in the annual number of analyses and the annual proportion of findings. In 1999, micro-pollutants were found in 20% of the filters included in the groundwater monitoring programme and in 23% of the analysed waterworks wells.

Chlorinated hydrocarbon, aromatic hydrocarbon and phenol

The most frequently detected organic micro-pollutants are trichlormethan trichloromethane (chloroform, chlorine-containing hydrocarbon) found in 9% of the analysed filters, benzene (aromatic hydrocarbon) in 8% and phenol in 2% of the analysed filters included in the groundwater monitoring programme. The corresponding findings in waterworks wells are considerably lower.

Methyl tert-butyl ether (MTB)

Methyl tert-butyl ether (MTB), an additive to petrol, is used to replace lead as an octane enhancer. Groundwater has been analysed for MTB in 28 filters with findings in one filter. Of the 164 waterworks wells analysed, MTB was detected in 17%, mainly in connection with pollution investigations. The average concentration was 0.29 µg l^{-1}, while the limit value for drinking water is 30 µg l^{-1}.

5.2.5 Pesticides and metabolites in groundwater

Since 1998, the groundwater monitoring programme has included 45 pesticides and metabolites. There has been an extension in pesticide analyses as only 8 pesticides were included for the first couple of years after 1989. The quality of the pesticide analyses of the initial years was questionable, and since the findings have not been confirmed by later analysis, this evaluation includes only results after 1993.

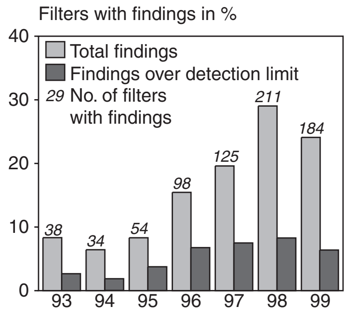

Figure 5.4 Pesticides and metabolites detected in analysed filters under the groundwater monitoring programme 1993-1999. Figures above the columns indicate the number of filters where pesticides and metabolites were detected. Source: *GEUS* (2000).

The detection frequency of pesticides and metabolites is lower in waterworks wells than in the groundwater monitoring programme and the agricultural monitoring progamme (table 5.5).

Table 5.5 Pesticides and metabolites detected during the period 1993-1999 Source: *GEUS (2000)*

Pesticides and metabolites for the period 1993-1999	Detected substances	Analysed filters	Filters with traces		Filters with traces ≥ 0,1µg l^{-1}	
	number	number	number	%	number	%
Groundwater monitoring	50	1,061	371	35.0	114	10.7
Agricultural monitoring	38	119	63	52.9	20	16.8
Waterworks wells	46	5,774	1,396	24.2	509	8.8

In 1999, pesticides or metabolites were detected in 24% of the analysed filters included in the groundwater monitoring programme and in 29% of the analysed waterworks wells. The limit value for drinking water was exceeded in 7% and 9%, respectively, of the filters and wells.

Pesticide detection frequency relative to age and depth

The deeper and the older the water is, the lower is the detection frequency of pesticides or metabolites. Some pesticides are, however, found down to a depth of 70 meters and, in isolated incidences, even deeper. Correspondingly, pesticides are found in groundwater in all age classes back to before 1950. The monitoring of groundwater shows that 50% of the groundwater generated during the past 25 years is contaminated with pesticides. The decreasing detection frequency with increasing depth seems to indicate that pesticides are transformed or diluted during the transport through the aquifers, or that the pesticides have not yet reached the deep-lying groundwater. The consumption of pesticides, and consequently also the load, was furthermore lower at the time of the generation of the deep-lying groundwater.

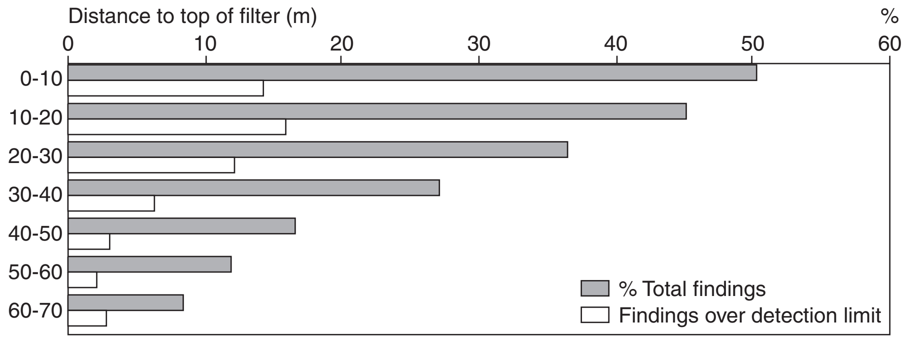

Figure 5.5 Detection frequency of pesticides and metabolites in groundwater at different depths in meters below ground level for the period 1993-1999, shown as filters with pesticides and filters with pesticides in concentrations exceeding the limit value for drinking water of 0.1 µg l^{-1}. Source: *GEUS (2000)*.

BAM and dichlobenil

Dichlobenil and its metabolite 2.6-dichlorobenzamide (BAM) are among the pesticides and metabolites most frequently found in groundwater. Dichlobenil is a herbicide that has been frequently used in built-up areas, along roads and railway tracks and in farm yards. BAM was detected in 24% of the wells, the concentration exceeding the limit value for drinking water in approx. 10% of the analysed wells.

Triazines and metabolites

Triazines and metabolites were also detected frequently in groundwater, although not in the same locations because these substances are very frequently detected in agricultural areas. In the agricultural monitoring catchments, triazines and their metabolites make up almost half of the total findings of pesticides and their metabolites.

Glyphosat and AMPA

Glyphosat and AMPA were found in isolated filters included in the groundwater monitoring programme, but not in any of the analysed waterworks wells. In the analysis of almost 200 samples from 45 filters included in the agricultural monitoring programme, glyphosat and AMPA were found in 8 filters. An analysis of the cause of the presence of glyphosat and AMPA in a 5 m deep well on the island of Funen did not provide an unambiguous explanation. The contamination may be a result of leaks in the covers of the wells that are situated 60-70 cm below ground level. It is, however, more likely that the contamination is a result of the infiltration of pesticide-contaminated water being led to the filters via worm holes, root canals, creaks and possibly sand.

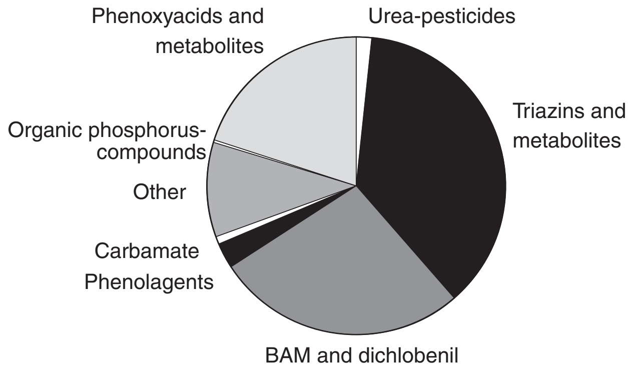

Figure 5.6 Distribution of abstraction well filters in which pesticides and metabolites were detected under the groundwater monitoring programme during the period 1993 – 1999. Source: *GEUS (2000).*

Detected pesticides are banned

The use of the pesticides found most frequently in groundwater is now prohibited or strictly controlled by the Danish EPA. The pesticides and their metabolites are, however, not prevented from reaching the groundwater now and for a long time to come.

Reporting of the pesticide consumption in the agricultural monitoring catchments started in 1998. The pesticide consumption is reported in terms of both the quantity of active substances sold and the frequency of application. In 1999, the total sales of pesticides complied with the reduction target of the 1997 Pesticide Action Plan.

5.3 Summary

So far, monitoring of heavy metals and hazardous substances has been limited – with the exception of pesticides in groundwater and heavy metals in the atmosphere – and the the assessment of most substances is yet made on a slender basis. The analyses do, however, provide an indication of the concentration levels of the substances and where in the environment these substances are present.

The analyses from 1999 have revealed that the water quality objectives for heavy metals are generally met in both watercourses and wastewater from treatment plants (table 5.2).

There has been a steadily declining trend in the concentrations of heavy metals in atmospheric deposition for the period 1989 – 1999.

Tributyl tin (TBT) differs from the other organic harzardous substances in that the TBT concentration in mussels in all locations in coastal waters exceeds the eco-toxicological evaluation criteria. The effect of TBT is reflected in snails as deformations of their genitalia.

Among the pesticides and metabolites, BAM, a metabolite of the herbicide dichlobenil, is the substance found most frequently in groundwater. The metabolite was found in 24% of the analysed waterworks wells and the limit value for drinking water was exceeded in 10% of these wells. BAM was found in the monitoring filters included in the groundwater monitoring programme at a corresponding frequency. Triazines and their metabolites were found in similar quantities in both waterworks wells and monitoring filters.

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6 Summary

Under the Danish Aquatic Monitoring and Assessment Programme 1998-2003, discharges, transport and effects of nutrients, heavy metals and hazardous substances in various areas of the aquatic environment are monitored. The programme was implemented in 1988/89 and concentrated mainly on nutrients then.

"Aquatic Environment 2000. State and trends – technical summary" provides a technical summary of the monitoring results.

6.1 Discharges to the aquatic environment

The climate in 1999 had an adverse effect on lakes and the sea because the high precipitation resulted in large inputs of nitrogen and phosphorus to the aquatic environment from diffuse sources.

Discharge from point sources

In 1999, 9,371 tonnes nitrogen, 1,238 tonnes phosphorus and 24,336 tonnes organic matter were discharged from point sources (table 6.1).

Table 6.1 Total inputs from various point sources to the Danish aquatic environment in 1989 and 1999. BOD_5 is a measure of organic matter.

	nitrogen		phosphorus		BOD_5	
Figures in tonnes	1989	1999	1989	1999	1989	1999
Wastewater treatment plants	18,000	5,134	4,470	581	36,400	3,508
Separate industrial dischargers	4,978	863	1,125	69	43,722	9,528
Stormwater outfalls	810	975	199	251	2,500	2,839
Freshwater fish farms	2,189	1,127	239	83	6,230	3,032
Scattered dwellings	1,280	971	440	221	4,850	3,813
Mariculture	322	301	44	33	-	1,616
Total	27,579	9,371	6,517	1,238	93,702	24,336

The point sources discharged to freshwater and directly to coastal marine waters. The input to freshwater of nitrogen, phosphorus and organic matter in 1999 constituted 60%, 61% and 44%, respectively, of the total point source input.

Discharges from point sources have been reduced by 66% nitrogen, 81% phosphorus and 74% organic matter since 1989 and the reduction targets for wastewater treatment plants and separate industrial discharges described in the Danish Action Plan on the Aquatic Environment I have been met.

Atmospheric deposition

The atmospheric deposition of nutrients to the aquatic environment derives from air emissions in both Denmark and other countries. Approx. 15% of the deposition on Danish marine waters is from Danish sources and is mainly concentrated along the coasts. The atmospheric nitrogen deposition on Danish territory was estimated at 210,000 tonnes in 1999, of which 120,000 tonnes were deposited on marine waters. The atmospheric nitrogen input to Danish marine waters is of a similar magnitude as the landbased input to Danish coastal waters.

A rough estimate shows that the atmospheric input to lakes constitutes 16% of the nitrogen load and 7% of the phosphorus load.

The atmospheric nitrogen input fluctuates concurrently with precipitation. There has been a reduction in the atmospheric nitrogen input since 1989, but the reduction is not yet statistically significant.

Leaching from agricultural land

The total net surplus of nutrients to agricultural land is expressed as the difference between the total input of especially commercial fertilizer and livestock feed, and the resulting output of milk, meat etc. The net surplus equals the potential loss to the atmospheric and aquatic environment.

Changes in agricultural practice and livestock production have resulted in a reduction in the total net nitrogen surplus by 37% and the phosphorus surplus by 32% since 1985.

The agricultural catchment monitoring programme shows that in 1999 approx. 20% of the area was excessively fertilized with nitrogen, but the overfertilization was significantly reduced in comparison with 1990/91. Based on agricultural practice in the catchments, the calculated nitrogen leaching from fields will be reduced by 28% over a number of years in relation to 1990/91, if the current agricultural practice is maintained.

In spite of significant annual variations there has been a reduction in nitrogen leaching from the rootzone since 1990/91. Annual variations in leaching from the rootzone are reflected in the upper groundwater in sandy soils. This observation does not apply to clayey soils.

42,500 tonnes phosphorus was applied to agricultural land in 1990. This is a reduction of 32% compared with 1985. The crop farms have a limited underfertilization while the phoshporus fertilization of the livestock farms increases with increasing livestock density.

Total input to the aquatic environment, and the sources

In 1999, the total input to Danish coastal waters via watercourses and discharges from point sources amounted to 101,500 tonnes nitrogen, 3,060 tonnes phosphorus and 46,600 tonnes organic matter (measured as BOD_5). The high input was due to the record-high precipitation in 1999 and the resulting high runoff causing a large diffuse nutrient loss.

Since the late 1980s, there has been a significant reduction in the total nitrogen and phosphorus input to coastal waters as a result of improved wastewater treatment. When the result is adjusted for variations in runoff it shows a minor reduction in the national diffuse nitrogen input. The national diffuse phosphorus input, however, was slightly increased.

The input of nitrogen and phosphorus from cultivated areas to watercourses and lakes was the predominant source with 84% and 53%, respectively, of the total input. The natural background loss constituted 11% of the nitrogen input and 19% of the phosphorus input. Discharges from point sources thereby constituted only 5% of the nitrogen input and 28% of the phosphorus input. Diffuse sources are consequently now the major input source of both nitrogen and phosphorus to the aquatic environment.

6.2 Heavy metals and hazardous substances

Monitoring of heavy metals and hazardous substances has been accorded greater priority since 1989 and is included in various parts of the monitoring programme.

Heavy metals

Monitoring of heavy metals in wastewater and watercourses shows a general fulfilment of the water quality objectives. The concentrations of heavy metals in the atmosphere have been steadily decreasing during the period 1989-1999. Lead concentrations, for example, have fallen by a factor of four, primarily as a result of the introduction of lead-free petrol. The concentrations of chromium and arsenic have been reduced significantly due to flue gas abatement measures at coal-fired plants and enhanced use of natural gas.

Pesticides

BAM, which is a metabolite of the herbicide dichlobenil, was found in groundwater in one out of four water supply abstraction wells and filters encompassed by the monitoring programme. It is the most frequently detected substance among pesticides and heavy metals.

In 1993, pesticides or metabolites were detected in almost 10% of the monitored filters and in about 25% of the filters in 1998 and 1999. In relation to 1998 the findings in 1999 were slightly reduced, indicating a possible stabilised or reversed trend. Findings exceeding the limit value were almost constantly at approx. 7% during the period 1996-99.

Hazardous substances

Tributyl tin (TBT) differs from the other organic pesticides in that the TBT content in mussels in marine waters is elevated in relation to the ecotoxicological evaluation criteria. TBT in snails results in deformation of the genitalia. TBT originates mainly from anti-fouling bottom paint on ships.

6.3 Status and trend of the environment

Groundwater

Total groundwater abstraction has decreased during the period 1989-99, mainly attributable to a reduction of 34% in the abstraction by the public waterworks. Dating of the groundwater shows that approx. 10% of the groundwater was formed less than 10 years ago, and possible effects of the action plans on the aquatic environment can therefore not yet be traced in the groundwater. Concentrations of nitrogen or phosphorus remain constant.

Due to the closing-down of water supply abstraction wells with high concentrations of nitrate, nitrate was detected in concentrations exceeding the limit value for drinking water of 25 mg nitrate l^{-1} in only 8% of the abstraction wells in 1999, whereas the limit value of 50 mg nitrate l^{-1} was exceeded in 2% of the wells. Nitrate concentrations exceeding the limit value were detected in 17% of the other filters encompassed by the groundwater monitoring programme.

Lakes

Phosphorus concentrations in the monitored lakes have been reduced by almost 50% since 1989 with the highest reduction in the most nutrient-rich lakes. The water in the lakes has become clearer with fewer algae. The number of submerged plants have increased since 1989, however, with a significant reduction in 1999 most likely as a result of deteriorated light conditions (Secchi depth), but in some lakes the increased water stage may have acted as a contributory factor. Despite the improvements, only 7 of the 31 monitored lakes have fulfilled the objectives. The quality objectives will not be met without a further reduction of the phosphorus inputs, and in particular the diffuse input as the primary phosphorus source.

Watercourses

Nitrogen concentrations have been reduced in most watercourses since 1989, when the variation in runoff is also considered. The reduction is most evident in streams with a sewage load, but a similar trend is seen in agricultural streams. Phosphorus concentrations were also reduced markedly in streams with wastewater discharges.

The state of the environment is assessed on the basis of the composition of benthic invertebrates (Danish Stream Fauna Index). The state of the environment in Jutland and on Funen is better than on Zealand, Lolland and Falster, and the environmental state is better in small watercourses than in large. Almost 40% of the monitored watercourses complied with the quality objectives in 1999. The most successful compliance with the quality objectives was found in watercourses with tightened objectives whereas the objectives were met less successfully in small as opposed to large watercourses. Further compliance with the quality objectives will only be achieved if the physical conditions in a number of watercourses are improved.

Marine areas

There was a strong stratification in the inner Danish marine waters in 1999 and severe oxygen depletion in the Belt Sea and the Arkona Sea and several coastal areas. The oxygen depletion was a result of increased nutrient inputs, which were enforced by the climatic and hydrographical conditions in 1999.

Nitrogen and phosphorus concentrations in coastal areas are influenced by the runoff. The general significant reduction in phosphorus concentrations since 1989 in addition to improved wastewater treatment seems to have stabilised the consequent positive effects on the marine environment. Nitrogen concentrations, however, have only fallen statistically significantly in the Limfjorden and not in the other coastal areas and open marine waters.

Nutrients in the fjords limited the production of phytoplankton for 40-200 days. There were marked variations between the fjords with a slightly more frequent phosphorus limitation than nitrogen limitation. Nitrogen was the potentially most limiting nutrient in the open marine waters.

There has been a reduction in the algal production in coastal areas since 1989 while the vegetation of macroalgae and eelgrass has been relatively stable. This may be ascribed to a relatively high input of nutrients in 1998 and 1999 because of high precipitation. There is no distinct trend in the phytoplankton production in the open marine waters while the depth distribution of macroalgae on reefs in the Kattegat was the lowest since 1990.

There was an increase in the number of benthic invertebrates in the inner marine waters from 1998 to 1999, presumably due to a higher abundance of food. A similar, but less distinct, trend is found in coastal marine areas although there are great variations between the various locations. None of the monitored locations meet the required objectives.

The present concentrations of nitrogen and phosphorus are not likely to result in a significant change of the state of the marine environment in the years ahead. Further improvements require a reduction of especially nitrogen.

Overall assessment

The general improvement of the aquatic environment is attributable to the reductions in the input of organic matter and nutrients since 1989. Although these reductions have resulted in an improvement of the environmental state, the monitoring results also show that the majority of the watercourses, lakes and marine waters still do not comply with the stipulated quality objectives. Nitrogen concentrations in groundwater are still high and there are many findings of hazardous substances.

A general compliance with the quality objectives will require further load reduction in lakes and marine waters and an improvement of the physical conditions in a large number of watercourses.

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7 Where can I read more?

A political and administrative description of the actions taken to ensure a cleaner aquatic environment in Denmark is provided in:

- *Danish Environmental Protection Agency (2000a)*: Vandmiljø-2000. Status og perspektiver for et renere vandmiljø (in Danish). 48 pp. Redegørelse fra Miljøstyrelsen, nr. 7/2000

Description of the various monitoring activities, including the Danish Aquatic Monitoring and Assessment Programme (NOVA 2003) is provided in:

- *Danish Environmental Protection Agency (2000b)*: NOVA-2003 (in Danish). Programbeskrivelse for det nationale program for overvågning af vandmiljøet 1998–2003 (in Danish). 397 pp. Redegørelse fra Miljøstyrelsen nr. 1

Further information on groundwater quality and quantity as well as groundwater monitoring is available in:

- *GEUS Geological Survey of Denmark and Greenland (2000)*: Grundvandsovervågning 2000 (in Danish). 137 pp. Særudgivelse
- *Nilsson, B., Brüsch, W., Morthorst, J., Vosgerau, H., Abildtrup, H.C., Pedersen, D., Jensen, P. & Clausen, E.V. (2000)*: Undersøgelse af landovervågningsboringerne DGU nr. 165.295 – 165.297 i LOOP område 4, Lillebæk, Fyns Amt (in Danish). – GEUS Geological Survey of Denmark and Greenland. Report 2000/47
- *Danish Environmental Protection Agency (1999a):* Fjernelse af metaller fra grundvand ved traditionel vandbehandling på danske vandværker. Vandfonden (in Danish). – Arbejdsrapport fra Miljøstyrelsen 17/1999

Further information on the environmental state of Danish watercourses and lakes is available in:

- *Bøgestrand, J. (red.) (2000): Vandløb og kilder 1999. NOVA 2003. Danmarks Miljøundersøgelser (in Danish). 126 pp. – National Environmental Research Institute. – Technical report No. 336*
- *Jensen, J.P., Søndergaard, M., Jeppesen, E., Bjerring Olsen, R., Landkildehus, F., Lauridsen, T.L., Sortkjær, L. & Poulsen, A.M. (2000): Søer 1999. NOVA 2003 (in Danish). 108 pp. – National Environmental Research Institute. – Technical report No. 335*
- *Grant, R., Blicher-Mathiesen, G., Jørgensen, J.O., Kloppenborg-Skrumsager, B., Kronvang, B., Jensen, P.G., Pedersen, M. & Rasmussen, P. (2000): Landovervågningsoplande 1999. NOVA 2003 (in Danish). 150 pp. National Environmental Research Institute. – Technical report No. 334*
- *Ovesen, N.B., Iversen, H.L., Larsen, S.E. & Svendsen, L.M. (2000):Afstrømningsforhold i danske vandløb (in Danish). National Environmental Research Institute. – Technical report No. 340*
- *Windolf, J., Svendsen, L.M., Kronvang, B. Skriver, J., Ovesen, N.B., Larsen, S.E., Baatrup-Pedersen, A., Iversen, H.L., Erfurt, J., Müller-*

Wohfield, D. & Jensen, J.P. (1997): Ferske vandområder – vandløb og kilder. Vandmiljøplanens Overvågningsprogram 1996 (in Danish). 112 pp. – National Environmental Research Institute. – Technical report No. 112

Further information on the environmental state of Danish fjords and marine waters is provided in:

- *Hansen, J. L.S., Pedersen, B., Carstensen, J., Conley, D., Christiansen, T., Dahl, K., Henriksen, P., Josefson, A., Larsen, M.M., Lisbjerg, D., Lundsgaard, C., Markager, S., Rasmussen, B., Strand, J., Ærtebjerg, G., Krause-Jensen, D., Laursen, J.S., Ellermann, T., Hertel, O., Skjøth, C.A., Ovesen, N.B., Svendsen, L.M. & Pritzl, G. (2000):* Marine områder. Status over miljøtilstanden i 1999. NOVA 2003 (in Danish). 230 pp. National Environmental Research Institute. – Technical report No. 333
- *Naturvårdsverket*. Svenske moniteringsdata 2000; www.nrm.se/mg/monitor.html.en

Further information on point-source discharges is available in:

- *Danish Environmental Protection Agency (2000c)*: Punktkilder 1999 (in Danish). Orientering fra miljøstyrelsen 16/2000.
- *Danish Environmental Protection Agency (1999b)*: Vandmiljø 1999. Status for vandmiljøet tilstand i Danmark (in Danish). 128 pp. – Redegørelse fra Miljøstyrelsen 1/1999

Further information on atmospheric deposition is provided in:

- *Hovmand, M.F. & Kemp, K.(2000)*: Tungmetalnedfald i Danmark 1999 (in Danish). p. 30 - National Environmental Research Institute. – Technical report No. 331
- *Ellermann, T., Hertel, O. & Skjøth, C.A. (2000):* Atmosfærisk deposition 1999. NOVA 2003. 120 pp. – National Environmental Research Institute. – Technical report No. 332

A description of legislation, guidelines and recommendations in relation to the aquatic environment is available in:

- *Danish Environmental Protection Agency (1988)*: Bekendtgørelse om vandkvalitet og tilsyn med vandforsyningsanlæg nr. 515 af 29. august 1988 (in Danish)
- *Danish Environmental Protection Agency (1990)*: Vandkvalitet og tilsyn med vandforsyningsanlæg (in Danish). - Vejledning fra Miljøstyrelsen 3/1990
- *Danish Environmental Protection Agency (1996)*: Bekendtgørelse om vandkvalitetskrav for vandområder og krav til udledning af visse farlige stoffer til vandløb, søer eller havet nr. 921 af 8. oktober 1996 (in Danish)
- *Danish Environmental Protection Agency (1996):* Bekendtgørelse om anvendelse af affaldsprodukter til jordbrugsformål nr. 823 af 16. september 1996 (in Danish)
- *Danish Environmental Protection Agency (1997)*: Boringskontrol på vandværker (in Danish). - Vejledning fra Miljøstyrelsen 2/1997
- *OSPAR (1998)*: Report of the Third OSPAR Workshop on Ecotoxcilogical Assessment Criteria (EAC), the Hague: 25-29 November 1996, Oslo and Paris Commissions, 1998

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