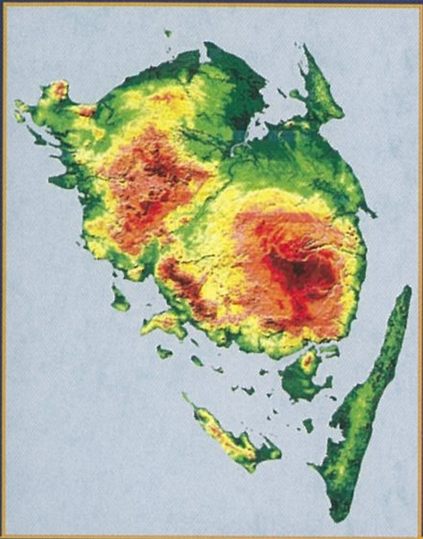
Aquatic Environment

of Fyn, Denmark, 1976-2000



- Streams and Lakes
- Coastal Waters
- Groundwater
- Environmental Impact of Wastewater and Agriculture

Fyn County

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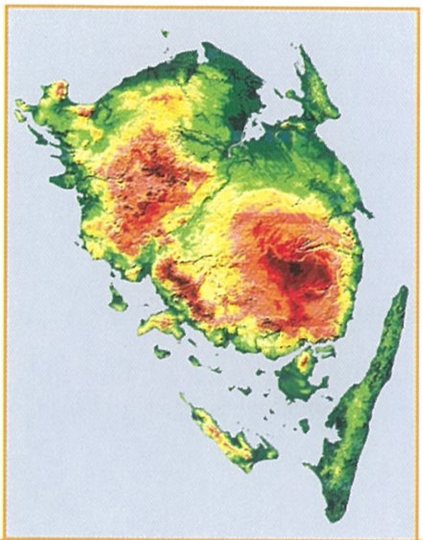

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Cover photo: Arreskov Sø, a lake in central Fyn. (Photo: Kjeld Sandby Hansen, Fyn County Council)

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Table of Contents

Table of Contents

Preface

Monitoring of the Danish aquatic environment has a relatively long history. Since the appearance of the first Danish Environmental Protection Act in 1973, this monitoring has been carried out by regional authorities in collaboration with the national environmental authorities. The regional authorities comprise fourteen county councils, and two municipal councils (located in Copenhagen - the capital of Denmark) that have county-status. The monitoring, comprising surface waters, groundwater, and the sources of pollution (i.e. households, industry, and agriculture), is the template for planning and administration in order to protect and improve the aquatic environment. Thus, it describes the present situation as well as trends in environmental quality.

In 1987, the Danish Parliament agreed on an 'Action Plan for the Aquatic Environment'. The main purpose was to reduce the impact due to the nutrients nitrogen and phosphorus, which also implied a strengthening of the previous national monitoring, including surface waters, groundwater, airborne pollution, and waterborne pollution from households, industry and agriculture. The counties carry out most of this 'Aquatic Monitoring and Assessment Programme', whereas the State concentrates on open marine waters and airborne pollution.

The national Action Plan and its derived monitoring programme meet the obligations defined in several important EU-directives, and in conventions for the marine environment (e.g. the Helsinki convention on protection of the Marine Environment of the Baltic Sea Area, 1974, revised 1992).

During the period 1988-1998, the 'Aquatic Monitoring and Assessment Programme' was directed primarily at organic matter and nutrients. However, in 1998 the programme was revised to incorporate heavy metals and hazardous substances too.

Since 1987, the investments in improved wastewater treatment and more sustainable agricultural practices have amounted to more than 2 700 mill. EUR, while the State and the county councils spend 27 mill. EUR annually on the monitoring programme in order to evaluate the effect of these investments.

Fyn County, comprising the island of Fyn and several smaller islands, is situated in the middle of Denmark ('the green heart of Denmark'). The County is thus located between the saline North Sea and the world's largest brackish water area, the Baltic Sea (see maps at the end of this report where also names of selected localities in Fyn County can be found).

Fyn County Council, one of the participants in the 'Aquatic Monitoring and Assessment Programme', has more than 25 years of experience in aquatic monitoring and assessment. Some of the previous results are published in the report "Eutrophication of Coastal Waters - Coastal Water Quality Management in the County of Funen, Denmark, 1976-1990" that was released in 1991.

The present report reviews the results and conclusions from 25 years of regional monitoring. However, it also includes data from investigations that date back to the 1970s, 1960s, and even to the beginning of this century. The report addresses people, decision makers, institutions, and organisations involved in or with interest in the aquatic environment.

In October 2000, the European Parliament and Council agreed on a 'Water Framework Directive' for the "protection of inland surface waters, transitional waters, coastal waters, and groundwater" (published and came into force 22 December 2000). The directive implies "administrative arrangements within river basin districts", not only to prevent deterioration of waterbodies and groundwater, but also to improve and restore these wherever possible. Obviously, Fyn County has all the assumed characteristics of a 'river basin district'. We therefore hope that our comprehensive and integrated presentation of the regional water cycle and regional water quality management will be an inspiration, not only in the implementation of the Water Framework Directive, but also for national and regional authorities involved in monitoring, assessment, and management of the aquatic environment worldwide.

Fyn County Council
September 2001

Ærø, an island in the South Fyn Archipelago. *Photo: Fyn County Council*

Summary and Conclusions

In 1987 it was recognised that Danish coastal waters were seriously threatened by nutrient input from land. This lead to political initiatives resulting in an Action Plan for the Aquatic Environment (APAE). Overall, the aim was to reduce the input of nitrogen and phosphorus by 50% and 80%, respectively. Consequently, measures were taken towards municipal wastewater treatment plants, industrial emissions, and the agricultural sector. Finally, a national monitoring programme was established in 1989 - including all types of surface waters, groundwater, as well as point sources and the more diffuse sources of the agricultural sector - in order to assess whether or not the aimed reduction in nutrient emissions was met. The regional authorities play an important role in carrying out this monitoring programme.

Denmark is administratively divided into 16 regional units: 14 counties and two large municipalities - both located inside the capital borders - and having county-status. According to the Danish Environmental Protection Act, these regional authorities are responsible for planning as well as monitoring the quality of the aquatic environment. Thus since the mid 1970s, Fyn County Council has enacted several generations of Regional Plans that include objectives for the quality of surface waters, and monitored the environmental conditions in watercourses, lakes, coastal waters, and groundwater in the region. This surveillance has also involved assessment of the effects of the pollution load that enter the aquatic environment from households, industry, and agriculture.

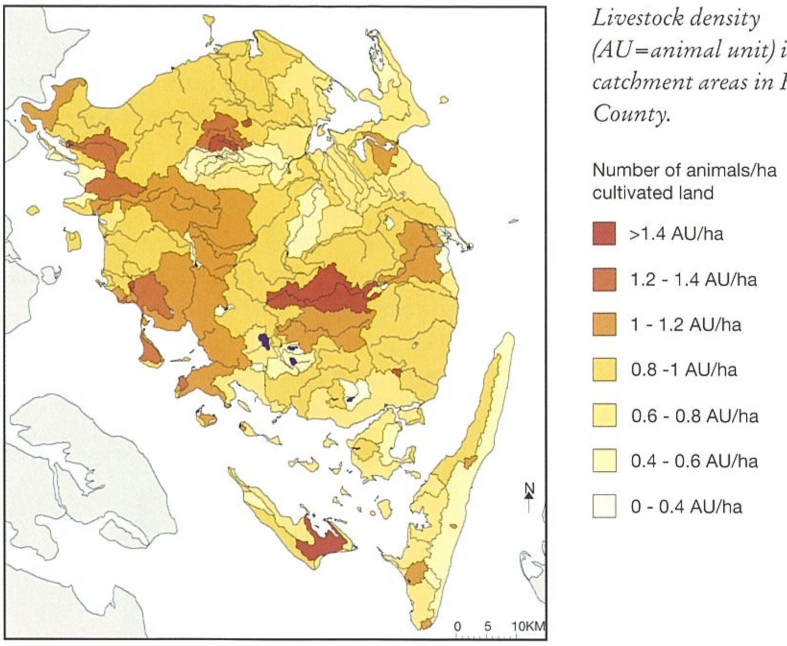
This report presents not only the results obtained from the national monitoring programme attached to the APAE, but also the results of 25 years of regional surveillance of the aquatic environment in Fyn County. The results are treated in context with the natural landscape and climate, human impact, and with particular emphasis on trends and the effectiveness of the measures introduced to control pollution and other human impact. Finally, conclusions are drawn from the results obtained, and it is assessed to what extent additional pollution control measures, as well as measures addressing improvement of the physical environment, are required in order to meet accepted objectives for the aquatic environment.

Human activities, nature and environment
Through the ages, human activities have affected the aquatic environment, both in physical terms, via the management of watercourses, land reclamation etc., and by discharges and losses of contaminants to groundwater, surface water, and the atmosphere.

Agriculture is the dominant form of land use in the County of Fyn. Thus, 69% of the area is farmed and 14% is urban area. Only 6% is registered as "natural" (forests, fens, meadows, moors, and salt mashes) compared with 9.6% for Denmark as a whole. Many natural areas have disappeared during the last hundred years. For example, 72% of the larger meadows and salt marshes have disappeared in the catchment of Odense Fjord (one-third of the total land area of Fyn). This drainage of wetlands has significantly reduced the number of habitats for both animals and plants. In addition, these areas can no longer serve as "filters" that can remove nutrients leaching from more intensively drained agricultural land to the water bodies.

Industrialisation, the introduction of flushable toilets in urban areas, and discharges of slurry and silage juices from agriculture resulted in extensive pollution of watercourses up until the 1970s, while agricultural consumption of artificial fertilisers in the 1960s and 1970s increased nutrient loads entering lakes, coastal waters, and groundwater. In the 1980s and 1990s, treatment of urban wastewater was greatly improved, and illegal discharges of slurry and silage juice essentially ceased. Since the beginning of the 1990s, agricultural consumption of artificial fertilisers has decreased, although the total application of fertilisers - as well as of pesticides - remains high and, consequently, continues to have undesirable effects on nature and the aquatic environment.

Since the 1950s, the agricultural sector has undergone considerable changes, primary in the form of fewer, larger farms and a higher degree of specialisation. The number of farms was reduced by 75% between 1955 and 1998. During the same period the number of cattle has fallen while the number of pigs have increased. Thus, production of pigs expressed in animal units (e.g. 1 AU = 30 porker, see also p. 26) increased by 40% between 1988 and 1998. Livestock are unevenly distributed, the density varying from less than 0.5 to more than 1.4 AU/ha agricultural land.



Livestock density (AU=animal unit) in catchment areas in Fyn County.

Climatic conditions

Precipitation, air temperature, and wind are of considerable importance in the interpretation of monitoring data for the aquatic environment, especially when extremes occur. Thus, the hydrological years - 1994/95 and 1995/96 - were the wettest (precipitation 1 012 mm) and driest (410 mm), respectively, during the 1900s. Precipitation was also unusually low in 1997, so that the infiltration of groundwater and the leaching of nutrients from the fields were significantly lower than normal from the summer 1995 to the end of 1997. Consequently, riverine nitrogen runoff entering the coastal waters in 1996 and 1997 was more than 50% below "normal". Further, in 8 out of 10 years in the period 1989-1998 the average annual temperature was considerably above the norm of 8°C, and four of these years were the warmest in the century.

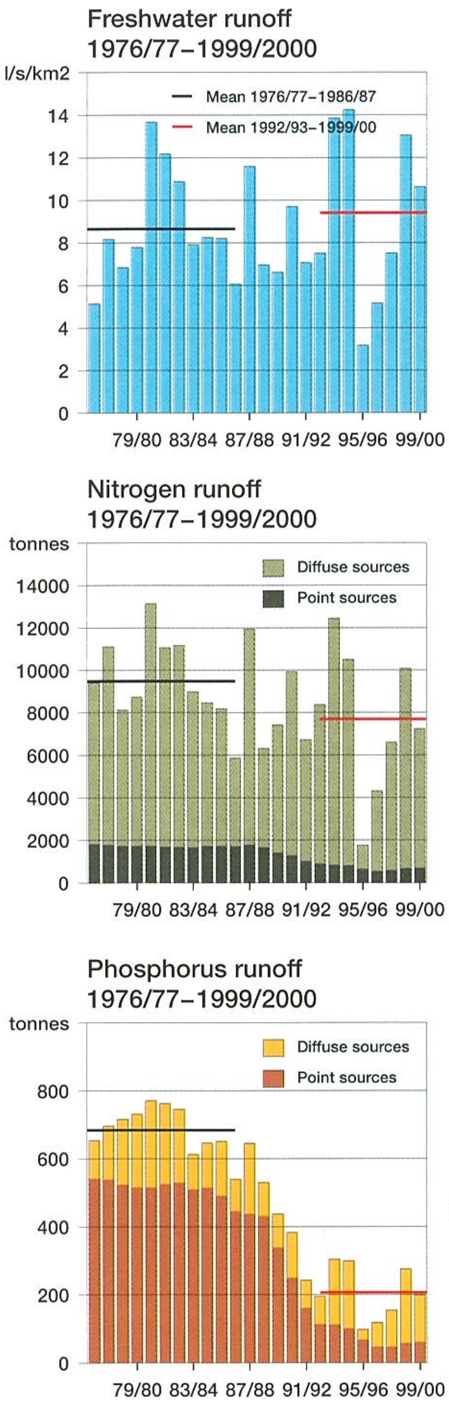
Wind is of particular importance for environmental conditions in coastal waters, as wind contributes to oxygenation of the waters, so reducing or preventing problems associated with oxygen depletion. In comparison with the latter half of the 1970s, there has been more wind to oxygenate water masses during the summer since the mid 1980s, except for the relatively calm summers in 1995 and 1997.

Out of the mean annual precipitation of 740 mm for Fyn County, about 60% evaporates, while about 40% flows to the sea, partly via drains and watercourses, and partly via groundwater.

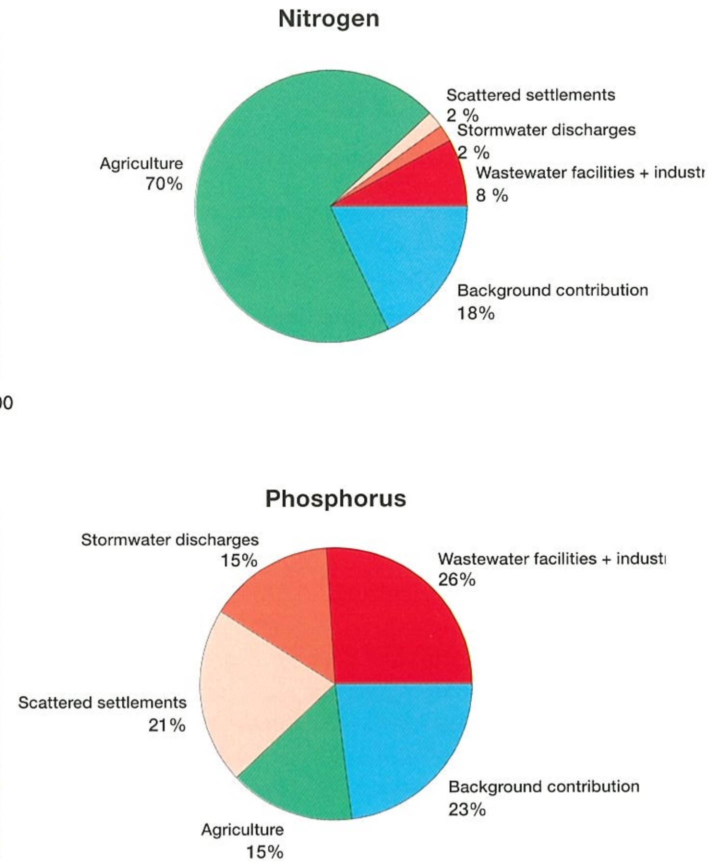
Sources of pollution

Households, industry, motor traffic, and agriculture affect the aquatic environment as a result of their release of a range of pollutants. These comprise 'natural' substances, such as nitrogen, phosphorus, oxygen-demanding materials (BOD) and heavy metals, and hazardous substances (e.g. pesticides). The impact includes both land-based discharges and atmospheric deposition.

Monitoring of the sources of 'natural' pollutants has been sufficiently comprehensive in order to produce reliable estimates of loads. Thus in 1999, nitrogen runoff to Fyn's coastal waters totalled 8 370 tonnes (24 kg N/ha), while runoff of phosphorus totalled 246 tons (0.71 kg P/ha), diffuse sources accounting for 90% and 75%, respectively (see figures below). Such calculations have, however, not yet been possible for heavy metals and hazardous substances that were just recently included in the national as well as the regional monitoring programmes.



Trends in total annual riverine runoff of fresh water, nitrogen, and phosphorus to the County's coastal waters during the period 1976/77 to 1999/00.



Relative importance of the primary sources of nitrogen and phosphorus input to the County's coastal waters. The values are means for the period 1992/93 to 1997/98.

Wastewater from households and industry

Wastewater facilities in the County have been fully modernised in accordance with the APAE and more restrictive regional requirements introduced to protect the most sensitive aquatic environments. Monitoring data show that discharges of phosphorus and nitrogen from municipal wastewater treatment plants at the end of 1999 were reduced by 93% and 71%, respectively, compared with averages for the period 1976-1987, prior to enactment of APAE. Since 1992, wastewater discharges from Denmark's municipalities and industries have met the overall APAE objectives of 80% and 50% reductions in emissions of nitrogen and phosphorus, respectively. However, significant improvements in wastewater treatment have occurred gradually since the 1970s as a result of wastewater planning by municipalities and counties.

Discharges from wastewater facilities can vary from year-to-year as a result of operational difficulties and variation in precipitation and, thus, the amount of wastewater treated. Efficient treatment of wastewater at large municipal facilities and by industries has contributed to discharges from scattered homes and urban stormwater drainage taking on greater relative importance. Discharges of wastewater from some 27 000 homes in rural areas that are not connected to a sewerage system are now the greatest single source of pollution of the aquatic environment with organic matter and phosphorus, whereas corresponding discharges due to urban stormwater drainage can be of the same magnitude as discharges from wastewater facilities and industries combined.

Wastewater may be an important source of hazardous substances. Monitoring results from wastewater treatment plants in the County show that facilities that receive wastewater from industry also receive the greatest amounts of hazardous substances. However, significant levels of these compounds (e.g. the detergent LAS and plasticisers) are also found at treatment plants that essentially receive wastewater from households. Although found in the effluents, the compounds are accumulated primarily in sewage sludge. This is a problem, as the levels are generally too high to meet Danish standards for the application of sludge to fields.

Investigations in the largest river in the County - Odense Å - show that when untreated wastewater is discharged by urban stormwater drainage, hazardous substances are more prevalent than during periods of dry weather. Out of a total of 63 different compounds present at elevated concentrations in the river during rain, 22 are considered to have originated from urban stormwater drainage.

Photo: Gunni Vilhelmsen, Fyn County Council

Egsmade wastewater treatment plant in the town of Svendborg. The facility is designed to treat a wastewater load equivalent to 105 000 person equivalents (PE, see p. 63 for definition)

Most industries in the County emit their wastewater to be treated in municipal plants. One of the few exceptions is Danisco Sugar, a factory located in the town of Assens. Previously, their direct discharge had a significant impact on the local coastal water, especially due to organic matter and nitrogen. However, in the mid 1990s the company established a wastewater treatment facility with extensive biological treatment and removal of nitrogen. Thus, the discharges are now less than 5% of the amounts previously released. The now-closed Stige Ø waste disposal site at Odense Fjord is similarly the point source that contributes by the largest amounts of contaminants to the aquatic environment. Protective measures to reduce leaching from the site are currently in the planning stage.

Atmospheric pollution from towns, industry, and motor traffic

Contaminants present in the atmosphere, for example ammonia originating from agriculture and nitrogen oxides from combustion processes, are deposited, sooner or later, onto the land or water bodies.

In 1999, some 14 700 tonnes of nitrogen (nitrogen oxides totalling 6 200 tonnes) and about 4 tonnes of phosphorus were discharged from the region to the atmosphere. Approx. half the amount of nitrogen was due to evaporation of ammonium-nitrogen associated with agricultural activities, while motor traffic and 'Fynsværket' power plant also contributed significantly. Emissions of phosphorus originated primarily from natural sources (drifting soil, pollen etc.) and burning of straw. A part of these emissions is deposited within the County (incl. its coastal waters) while the remainder is exported to other regions. Likewise, nitrogen and phosphorus originating from other regions are deposited on Fyn.

The measured wet deposition (i.e. with precipitation) and estimated dry deposition combined was 24 kg N/ha and 0.20 kg P/ha on the County's land area in 1999, whereas 15 kg N/ha and 0.13 kg P/ha were deposited on the County's coastal waters. Depending on precipitation, atmospheric deposition varies from year-to-year. In 1999, atmospheric loading of the coastal waters contributed with approx. 42% of the nitrogen and 17% of the phosphorus entering these waters. This contribution is, thus, of significant importance compared to riverine nutrient loading, and atmospheric nitrogen deposition may in summer even exceed riverine nitrogen input.

Regional measurements of the nitrogen content in precipitation have been carried out since the 1950s. They show a 60% increase in inorganic nitrogen (when corrected for variations in precipitation) from 1957-1961 to 1990-1999 when concentration averaged approx. 1.6 mg N/l. In addition, a comparable increase in dry deposition is suggested.

Motor traffic and 'Fynsværket' power plant are the primary emitters of nitrogen oxides. During the period 1953-1991, emissions from the power plant increased five-fold due to an increasing demand for electricity and central heating. However, in 1991 a new boiler was installed and emissions were reduced considerably. Increasing motor traffic, up until 1990, has also significantly increased emissions of nitrogen oxides. However, these emissions have since been reduced by 30% due to the requirement of a catalytic converter to be fitted on all new petrol-driven private vehicles. Present day emissions are thus of the same magnitude as those at the beginning of the 1980s.

Agriculture

Agricultural activities result in the loss of nutrients and pesticides to the environment. These losses partly affect surface water and groundwater, primarily due to leaching, and partly the atmosphere due to evaporation of ammonia and spraying of pesticides. A certain amount of pollutants emitted to the atmosphere may subsequently enter the aquatic environment as a result of atmospheric deposition.

Slurry spreading.

Photo: Bjarne Andresen, Fyn County Council

A nitrogen balance drawn up for agriculture in Fyn County shows that during the period 1995-1997 agriculture annually consumed some 41 000 tons of nitrogen. Approximately one-third of this amount was utilised in agricultural products that were exported, while the remaining two-thirds was lost to the environment. Since the mid 1980s, this surplus has been reduced by about 25% - equivalent to the reduction for Denmark as a whole. However, approx. 27 000 tonnes N/year are still lost to the environment from Fyn County. One-third is lost to the atmosphere via evaporation of ammonia, approximately one-third is leached to groundwater, while the remaining third of the surplus is leached to surface waters, and is equivalent to the amount of nitrogen in untreated wastewater from some 2 million people.

During the period from the mid 1980s to the mid 1990s, the production of animal protein (meat, milk, eggs) in Fyn County (and Denmark as a whole) increased by 22-25%. Without this increase, surplus agricultural nitrogen would have been reduced by about 40%. Thus, increased production has reduced the effectiveness of APAE-measures enacted to reduce agricultural impact on the aquatic environment.

Nitrogen leaching - and riverine N-runoff - depend on a number of factors relating to farming practices and to climactic conditions, being best explained by the total amount of nitrogen applied to fields. Other important factors are the types of crops grown and crop rotation, and the handling of manure. Overall, precipitation obviously determines the amount of the surplus nitrogen that is leached to surface water and groundwater.

Investigations by Fyn County Council in six fields in clayey soil areas show that an average of 70 kg N/ha is leached annually from the root zone, amounting to 25-45% of the nitrogen applied to crops. The average concentration of nitrogen in the water leaching from the fields was 19 mg/l, equivalent to 84 mg nitrate/l, which is more than three times the nationally recommended maximum limit for drinking water. Accordingly, nitrogen levels in streams draining agricultural areas are 4-6 times higher than those in streams draining 'nature' areas.

Evaporation of ammonia - primarily from manure - is the most important source of nitrogen emission to the atmosphere, exceeding those from motor traffic, power stations, industries etc. The primary sources are stalls and manure piles/slurry tanks. The evaporation have increased in recent years as many farms have invested in stalls with deep bedding, partly in order to improve animal welfare. In addition, leaching from fields has increased, as the degree of utilisation of nitrogen present in bedding material is considerably lower than that in slurry. The total regional evaporation of ammonia is estimated to be 8 500 tonnes of nitrogen, representing 10% of the ammonia evaporating from Denmark as a whole. Approximately 50% of the regionally evaporated ammonia is exported to coastal waters and adjacent areas of land.

The average density of livestock in Fyn County is approximately 0.9 AU/ha agricultural land, though there is considerable local variation (0.5 - 1.4 AU/ha). Such large variation results in considerable local variation in leaching of nitrogen, and in the evaporation and subsequent deposition of ammonia.

Despite the fact that the total regional consumption of artificial fertilisers and manure has been reduced by 15% since the late 1980s, and although manure has been used more efficiently in the last 5-6 years, the agricultural nitrogen impact on the environment still remains high, and far from meeting the APAE's objective of a 50% reduction in nitrogen emissions. Thus, the reduction in riverine nitrogen runoff after implementation of the APAE can, to a considerable extent, be attributed to improved treatment of wastewater at municipal wastewater facilities. Thus, it is assessed that nitrogen runoff from diffuse sources (primarily agriculture) to the sea has been reduced by maximally 10-15% compared to the level prior to enactment of the APAE, when runoff is corrected for annual variation in freshwater discharge.

Measurements show that relatively large losses of phosphorus also occur from agricultural land. In 1999, approx. 75% of the regional riverine phosphorus runoff to coastal waters originated from diffuse sources, primarily agriculture and scattered homes, with the former making the largest contribution. However, as 1999 was an unusually wet year, the loss of phosphorus from agricultural land is regarded normally to constitute up to half of the phosphorus originating from diffuse sources associated with human activities.

Streams

Stream quality - reflected in the diversity of stream-dwelling organisms - depends on the amount and quality of water, and on physical conditions, all factors that are affected by a range of human activities.

The quality of the larger streams has improved considerably during the last 10-15 years. This is reflected in the invertebrate assemblages. Thus, when assessed by the Danish Stream Fauna Index (DSFI) the proportion of sites with 'acceptable' conditions has doubled to approximately 60%. The main factor responsible is the marked reduction in the amounts of oxygen-consuming substances due to an effective treatment of municipal wastewater, though a more environmentally friendly stream management has also played a role. A more gentle weed-cutting practice has also positively affected other biological components, e.g. increasing populations of trout (*Salmo trutta*) fourfold. Fish populations have also benefited from the removal of approx. 70% of the obstacles found in the larger streams that Fyn County Council has carried out during the past 10 years. This has especially improved the spawning success for sea trout.

Photo: Bjarne Andresen, Fyn County Council

Kongshøj Å - an unregulated stream of high biological diversity.

In contrast, environmental conditions in the smaller streams have only improved slightly, as only some 20% now have acceptable conditions, although heavy organic pollution due to slurry and silage juice from agricultural activities are significantly reduced. The primary reason for the present quality of these streams is poorly treated wastewater from scattered homes and villages in rural areas. However, poor physical conditions in the watercourses, a result of hard-handed management and former regulations (straightening, deepening), also play a role.

Pesticides

Despite the general improvements in stream quality, occasional input of pesticides represents a serious environmental problem. During the period 1988-1999, approx. 20% of the biological monitored sites experienced acute damage, reflected by extermination or heavily reduced populations of crustaceans and aquatic insects. This has had additional biological effects, e.g. resulting in the occurrence of mats of filamentous algae on the stream bottom due to the lack of invetebrate grazing.

Such episodes of poisoning of course reduce the effectiveness of the considerable investments in wastewater treatment. Without these about 10% more of the County's larger streams would have

Arreskov Sø - the largest lake in Fyn County.

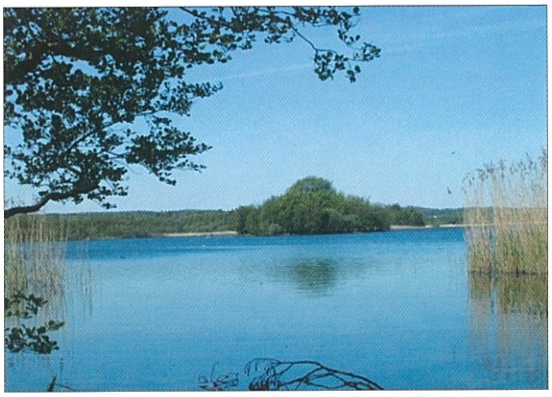


Photo: Kjeld Sandby Hansen, Fyn County Council

acceptable environmental conditions. The problem appears to be in decline due to greater care in the handling of pesticides used in agriculture and market gardening, the main consumers of pesticides.

During the period 1994-1997, Fyn County Council investigated 237 water samples from various streams, springs, and drains for the presence of 99 different pesticides. In all, 33 pesticides or degradation products were found. The most frequently detected substances were isoproturon and glyphosate, two of the most commonly used pesticides in Denmark.

Glyphosate - the active agent in products such as 'Roundup' - occurred at highest concentrations of all pesticides - up to 11 µg/l in a field drain. This is remarkable, as during the process of its approval in Denmark it was assumed that neither this substance nor its degradation product, AMPA, would leach or percolate.

The investigations show that pesticides are found more frequently in streams that solely drain agricultural areas, or that drain catchments with a variety of pesticide consumers (agriculture, industry, public institutions, and households), than in 'forest streams'. The results also indicate that pesticides mainly enter streams via field drains, especially during the spraying season, and only to a minor extent through wind drift. However, pesticides are also discharged from wastewater treatment plants.

Bacteriological water quality

Despite the effective treatment of wastewater at municipal facilities, the hygienic quality of water in streams remains unsatisfactory. Thus, although the numbers of intestinal bacteria have decreased, streams in the County may still contain 500-1 000 *E. coli* bacteria/100 ml water. In comparison, the average number of these bacteria in the County's bathing waters is less than 10 *E. coli*/100 ml.

Lakes

Only 4 of 34 lakes investigated meet objectives in the County Regional Plan. The primary reasons are the input of poorly treated wastewater from scattered homes not connected to a sewerage system, and the addition of nutrients from agricultural land. Furthermore, many lakes have accumulated nutrients in their sediments over a period of years, nutrients that partly originate from earlier discharges of wastewater. These nutrients, and phosphorus in particular, are released from the sediments resulting in unwanted growth of phytoplankton.

Although objectives have not been met, several lakes have experienced a significant decrease in phosphorus content due to improvements in municipal wastewater treatment in their catchments. The reduction in nutrient concentrations in lake water has, however, often been insufficient to limit phytoplankton growth and thus to improve water transparency.

There are, however, a few examples of improved transparency, partly as a result of reduced input of nutrients, partly as a result of "biomanipulation". This in-lake treatment involves removal of zooplanktivorus fish by net fishing and/or release of large numbers of piscivorus fish (fry of the pike *Esox lucius*). This allows the zooplankton to control algal growth by grazing, so reducing the abundance of algae and thereby improving secchi depth. However, it is evident that good environmental quality can only be sustained if the input of nitrogen and phosphorus is reduced to a very low level.

The interaction between nutrient loading, water chemistry and biological structure in lakes can be nicely exemplified by the development in the County's largest lake, Arreskov Sø. After 1983, when wastewater discharges from a nearby town were cut off, water quality declined due to the release of phosphorus that had accumulated in the sediments. However, in 1991-1992 a dramatic change took place due to the death of the majority of the lake's fish populations. This altered the biological structure of the lake and significantly improved transparency. Thus, a greater abundance of zooplankton resulted in fewer algae which, in turn, allowed submerged plants to spread over a large part of the lake. The more abundant aquatic vegetation allowed the lake to support greater numbers of mute swans (*Cygnus olor*) and coots (*Fulica atra*). In the summer of 1999, however, conditions in the lake deteriorated as a result of extensive blooms of cyanobacteria which, in turn, caused the virtual disappearance of the lake's submerged plants. The decline in environmental quality is attributed to a great nutrient runoff in the autumn of 1998 and spring of 1999, and to a relatively large number of fish fry that preyed on zooplankton to such an extent that these were no longer able to limit the growth of cyanobacteria.

According to investigations made by Fyn County Council, some 50-80% of the nitrogen entering the County's lakes is subsequently lost from them. The largest part is lost to the atmosphere due to denitrification, whereas a minor part is deposited in the sediment. Phosphorus is also lost from water as it passes through the lakes. Some 15-25% of the phosphorus that annually enters the lakes binds to bottom sediments, though considerable amounts can be released to the water during the summer. Thus, lakes effectively function as 'natural wastewater treatment plants' when, for example, streams flow through them. In so doing, they reduce the amount of nutrients entering the coastal waters.

Coastal waters

The coastal waters in the County are affected by inputs of nutrients and hazardous substances from the land, atmosphere, and adjacent water masses. Monitoring carried out by Fyn County Council since 1976 shows that the objectives of the Regional Plan are still not met, neither for the open coastal waters, nor the adjoining shallow water areas, fjords, and coves.

Nitrogen and phosphorus loading

Phosphorus input to the coastal waters has been reduced by approx. 75% due to improved treatment of wastewater, compared with the period 1976-1987 prior to the enactment of the APAE. In contrast, land-based nitrogen input has only been reduced by 20-25%. However, loadings of both phosphorus and nitrogen show considerable year-to-year variation as a result of annual variation in the amount of precipitation and runoff. Thus compared with the period 1976-1987, the reduction loads of phosphorus and nitrogen were 64% and 9%, respectively, in the relatively 'wet' year 1999, whereas the reductions were 85% and 65%, respectively, in the particularly dry year 1997. These variations in nutrient load are of course reflected in environmental conditions in the coastal waters. Thus during winter, the levels of nitrogen and phosphorus in coastal waters are highly correlated with the riverine runoff of these nutrients.

Environmental conditions in coastal waters

During summer, water masses in the more open and deeper parts of the coastal waters are generally stratified, with relatively fresh (and light) water from the Baltic Sea at the surface, and more saline (and heavier) Kattegat water near the bottom. This stratification has - together with the riverine runoff - important implications for phytoplankton growth and, thus, the prevalence of oxygen depletion in hypolimnion due to sedimentation and decomposition of the algae.

The concentration of phosphorus in coastal waters was significantly reduced during the period 1976-1999, while there was no significant trend for nitrogen. Low nutrient runoff in 1996 and 1997 resulted in especially low nutrient concentrations in coastal waters, reflected in low growth of phytoplankton and, consequently, improved transparency. However in 1998 and 1999, runoff of phosphorus and nitrogen returned to their 'normal' levels, resulting in greatly increased growth of algae.

Oxygen depletion (or hypoxia) occurs annually, though the distribution, degree, and duration vary. The phenomena was first recognised in summer of 1981, resulting in the death of fish in a large part of Denmark's inner coastal waters, including those around Fyn. In 1996 and 1997, oxygen conditions were unusually good, primarily due to low growth of phytoplankton (see above), whereas the most serious episode of oxygen depletion in Denmark's inner coastal waters, especially around Fyn and along the east coast of Jutland, was registered in the late summer of 1999. Historical surveys in the Little Belt at the beginning of the 1900s show that oxygen depletion also occurred then, but only in the deepest depressions in the sea bed. Thus, the area that is nowadays affected has increased nearly fivefold.

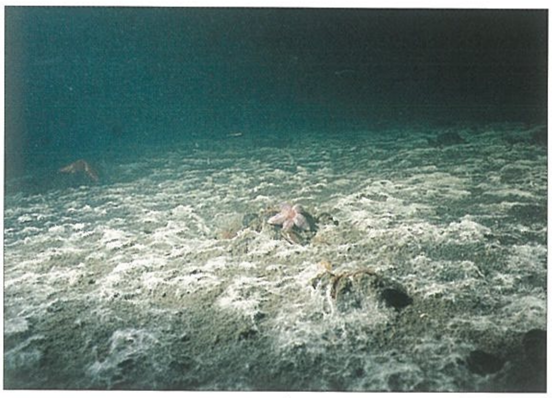


Photo: Nanna Rask, Fyn County Council

Oxygen depletion at the bottom of Nakkebølle Fjord.

When compared with surveys for the early 1900s, recent investigations of benthic vegetation show that the depth limit of eelgrass (*Zostera marina*) has been reduced from 9-10 m to 5-7 m. Accordingly, the depth limit for macroalgae in the Little Belt has fallen from 30-35 m to 10-12 m, and the natural vegetation has been considerably reduced and replaced by pollution-tolerant taxa such as filamentous algae and sea lettuce (*Ulva lactuca*) in many smaller fjords and coves. These remarkable changes are primarily the result of the increased nutrient loads, as high nutrient concentrations promote the growth of phytoplankton which, in turn, reduces transparency and, thus, the depth distribution of macroalgae and eelgrass.

In fjords and coves in which wastewater was previously a dominant source of pollution, measures to reduce this impact have, since the beginning of the 1990s, been successful for phosphorus, but also for nitrogen during summer. Thus, improvements in environmental quality in the affected areas, notably Odense Fjord and Kertinge Nor, have occurred.

When viewed in the long-term, statistical analyses indicate a number of positive trends in the environmental factors examined, especially during the last 10 years. For example, there has been a significant decrease in phosphorus concentrations, a reduction in algal biomass, improved transparency, and, in certain areas, improved oxygen conditions during the spring. The reduced phosphorus loads may increase the potential of this nutrient to be a limiting factor for the phytoplankton production.

Hazardous substances

In cooperation with the County Council's of Vejle and Sønderjylland, Fyn County Council has investigated the regional prevalence in marine sediments of 110 hazardous substances, representing eight chemical groups, and including several of those most commonly used in industrial products and, thus, also in households. Representatives of all the groups - phthalates, nonylphenols, p-triesters, chlorobenzenes, phenols, PAHs, LAS, and pesticides - were present. The highest concentrations were generally found in coves and the upper reaches of fjords located near the mouths of rivers or near direct discharges of wastewater. Many substances were present at concentrations which, when assessed according to international guidelines and sediment quality criteria, may be expected to be biologically harmful.

In addition to the afore-mentioned substances, investigations of organotin compounds (TBT) were carried out at three sites in Odense Fjord in 1998 and 1999. One of the primary uses of TBT is as antifouling paint on the hulls of ships, thus it is expected to be used in a local shipyard. Accordingly, TBT was found in common mussels (*Mytilus edulis*) from all stations examined, and at concentrations that far exceeded guiding ecotoxicological threshold values established by the Olso-Paris Convention (OSPARCOM). TBT has a number of effects on organisms. In Odense Fjord 25-57% of female periwinkles (*Littorina littorea*) closest to the shipyard developed male characters (intersex), whereas those further from the source only had minor disruptions of their hormon balance. Male periwinkles were affected too.

In 1998 and 1999, the common mussels in Odense Fjord were also examined for their content of heavy metals, PAHs, and PCBs. All these compounds were found, some at concentrations considered critical for animal life. Thus, PCB levels were of the same magnitude as guidance ecotoxicological effect values, at and above which adverse biological effects cannot be excluded. The same applies to one of the PAHs examined.

Bulk sampler for collecting atmospheric deposition.

Photo: Inge Bendixen, Fyn County Council

Bathing water quality

The regular control of bathing water quality at the County beaches has shown a marked general improvement over the last 20 years. Thus in 1982, 95% of samples of bathing water contained fewer than approximately 900 *E. coli* bacteria/100 ml water, whereas in 1998 this figure had declined to fewer than 200 coli bacteria/100 ml water. This improvement is the result of the considerable efforts carried out by the municipalities in the County to reduce wastewater loading of coastal waters, via direct discharges and indirect discharges occurring via streams.

Groundwater

Groundwater is formed during winter by percolation of precipitation. On its way, the water takes up and loses substances. Groundwater quality is, therefore, especially dependent on land use and soil characteristics. As the formation of groundwater normally takes many years, contaminants in the groundwater abstracted today for drinking water may originate from human activities of many years ago.

Nitrate and dissolved salts

In contrast to other Danish regions, deeper-lying groundwater in Fyn County shows only limited contamination with nitrate. This is due to groundwater aquifers generally being protected by a layer of clay in which nitrate is degraded. Thus, the concentration is less than 5 mg nitrate/l at 83% of the waterworks, representing 92% of the drinking water supply. Since 1996, only six, smaller waterworks have exceeded the recommended upper limit of 25 mg/l, and no waterworks supply water with nitrate concentration exceeding the maximum limit of 50 mg/l.

However, the protective clay layer is locally thin or absent, resulting in contamination with nitrate. These areas are, of course, unsuitable for the abstraction of groundwater for drinking water. Where shallow groundwater is abstracted, such as in many private boreholes and wells, the quality of the water is often affected by the leaching of nitrate from agricultural land, and the nitrate concentration often exceeds 50 mg/l.

In many areas, groundwater has an elevated chloride concentration due to percolation of chloride-containing salts present in fertilisers or in salt spread on roads, and continuously increasing chloride concentrations have been found at a number of waterworks. Thus, the recommended upper limit of 50 mg/l is exceeded in one-third of the water abstracted for drinking water. The impact of salt spread on roads will be considerably reduced by changes in salting practices and distribution methods developed by Fyn County Council.

Just over half the total volume of water abstracted has a sulphate concentration exceeding the recommended upper limit of 50 mg/l, and the sulphate concentration is increasing in a large number of waterworks boreholes. If the rate of increase does continue, the maximum permitted concentration of 250 mg sulphate/l is expected to soon be exceeded in many boreholes. The increase in the sulphate concentration is attributed primarily to the oxidation of sulphur compounds present in the soil as a result of a falling water table (due to excessive groundwater abstraction) or to percolating nitrate. Sulphate present in fertilisers may, however, also contribute to increasing sulphate concentrations.

Oxygenating stairs at a waterworks.

Photo: Lars Gejl, Biofoto

Hazardous substances

Groundwater is contaminated by pesticides and other hazardous substances at many locations in the County. A total of 30 different pesticides and degradation products were detected, 2,6-dichlorobenzamide (BAM) being the most prevalent. The proportion of investigated boreholes containing BAM is high, the substance being present in 110 (22%) of 493 boreholes tested. However, BAM is far most prevalent in shallow boreholes. Concentrations seem to be decreasing in some contaminated boreholes.

Contamination with other hazardous substances, such as chlorinated solvents and petrol compounds, has been detected at many locations. Such contamination occurs often in towns, and can usually be traced back to contaminated industrial sites, petrol stations, and dry cleaners. Chlorinated solvents have been detected in 10% of the active boreholes tested, and eight waterworks' boreholes have been closed for that reason.

MTBE, an additive to petrol, has been found in high concentrations at contaminated petrol station sites. In a limited survey, MTBE has been detected in 6 of 19 active waterworks' boreholes. Thus, this unpleasantly tasting compound appears to pose a considerable threat to the quality of groundwater.

Groundwater resources

Annual variation in precipitation is reflected in variation in the groundwater table. Thus, the groundwater table was extremely low in both 1977 and 1997 following years with low amount of precipitation. However, measurements carried out in 1999 indicated that groundwater had returned to its normal level due to the large amounts of precipitation in 1998-1999.

In 1998, 47 million m^3 groundwater was abstracted in Fyn, of which 41 million m^3 was abstracted for drinking water, primarily by waterworks. The remaining 6 million m^3 was abstracted primarily for irrigation in agriculture and horticulture, and for industrial purposes. The volume of water abstracted annually has fallen by some 20 million m^3 since the mid 1980s, primarily due to reduction of leakage from the water supply networks and by the introduction of water meters and increased taxes on the consumption.

Achievement of objectives and concluding remarks

Based on Fyn County Council's monitoring programme, it can be concluded that the objectives set in the Regional Plan are still not met for the majority of surface waterbodies in the County. In addition, hazardous substances have been found in groundwater from a large number of investigated boreholes, though there is uncertainty as to what extent groundwater used in water supply is affected. The reason that the objectives established have not been met are the effects of current and previous human activities such as the discharge of organic matter, nutrients, heavy metals, hazardous substances, and physical deterioration of the environment.

However, improvements have taken place. Thus, the municipalities (public wastewater treatment plants), industry and agriculture have used many resources to reduce their loading of the aquatic environment. Wastewater discharges from municipal facilities and industry have been reduced considerably over the last 10 years, now meeting the APAE I objectives of a 50% and 80% reduction in emissions of nitrogen and phosphorus, respectively, as well as more restrictive regional requirements for the discharge of these nutrients. In contrast, the estimated nitrogen runoff from agricultural land is only reduced by 10-15% compared to the period prior to enactment of the APAE I.

A nitrogen balance set up for agriculture in the County shows that utilisation of nitrogen improved from the mid 1980s to 1997, reducing the total surplus of nitrogen by 25%. However, as a large proportion of this surplus is lost to the atmosphere, direct relationships between riverine nitrogen runoff and total losses of nitrogen can not be established. A major reason for the small reduction in nitrogen runoff is an increase in animal production since the adoption of APAE I. The above mentioned nitrogen balance shows that - with an unaltered animal production - the surplus of nitrogen would have been reduced by about 40%, mainly due to improved utilisation of nitrogen.

The APAE II, enacted in the spring 1998, includes a reduction in fertiliser norms for agricultural crops, sharpened requirements for the utilisation of nitrogen in manure, better utilisation of fodder, use of catch-crops, and the establishment of water meadows to retain/remove nutrients. These initiatives are, however, only expected to reduce nitrogen loading of aquatic habitats provided that animal production is unaltered during the timescale of the plan. Provided that these assumptions are met, a 50% reduction in nitrogen loading of Denmark's inner coastal waters - including those of Fyn County - will probably not be obtained. Neither does the plan necessarily ensure that nutrient loading is sufficiently reduced to meet the objectives for local waterbodies (e.g. lakes, fjords, and aquifers). One of the 'dark horses' is evaporation of ammonia from agricultural areas, although a national action plan for reducing this impact is expected in 2001.

Fyn County Council has identified additional measures necessary to improve the aquatic environment and meet the objectives in the Regional Plan. Thus, the regional environmental authorities (i.e. the County Councils) should be provided with the necessary legislation and economic support to produce and carry out specific action plans for regional water bodies. Further, these action plans should be able to apply measures to point sources as well as to diffuse sources, being the most obvious tool to regulate the heavy environmental impact from intensive livestock rearing. According to the APAE II, similar action plans are already going to be incorporated in the Regional Plan for appointed areas of special drinking water interests, whereas comprehensive action plans for catchments, including surface waters as well as groundwater, are presupposed in the EU Water Framework Directive,

Although comprehensive knowledge exist about the effects of organic matter and nutrients on aquatic ecosystems, there is no collective overview of the environmental effects of the wide range of hazardous substances found in surface water and groundwater. This calls for intensified monitoring and research.

Achieving objectives for the aquatic environment set out in Fyn County Council's Regional Plan, and in national and international plans, demands focus on a range of measures to improve environmental quality:

- **Reduction in losses of nitrogen from agriculture to surface water, groundwater, and the atmosphere. A considerably greater reduction than 50% in nitrogen input is needed for waterbodies that are specially vulnerable and given high environmental priority**
- **Reduction in atmospheric deposition of nitrogen originating from other sources**
- **Reduction in losses of phosphorus from agriculture to surface water**
- **Improved treatment of wastewater from private households in rural areas**
- **Reduction in loading arising from urban stormwater discharges**
- **Improved hygienic quality of wastewater discharged from municipal treatment plants**
- **Efforts to prevent pesticides, other hazardous substances, and heavy metals entering the water cycle**
- **Restoration of streams, lakes, and enclosed marine areas, and environmentally friendly management of streams**
- **Reestablishment of wetlands, notably water meadows, adjacent to streams, lakes, and coastal marine habitats**
- **Catchment-based action plans for groundwater as well as surface water in order to reduce the impact of pollutants - beyond general national demands - to meet the specific objectives of the County's Regional Plan, and taking the guidelines of the EU Water Framework Directive into consideration**

A view from Svanninge Bakker looking over the town of Fåborg and the South Fyn Archipelago. Photo: Bert Wiklund

1 Nature and Human Impact

The landscape of Fyn

The last ice age, from 11 500 to 100 000 years ago, was primarily responsible for shaping the landscape of Fyn County as we know it today (Figure 1.1). Only in a few places is it possible to directly see deposits from earlier periods in the Earth's history. One example is the chalk deposits at Klintholm on eastern Fyn. The material constituting Fyn was scraped up from the bottom of the Kattegat and Baltic Sea by ice masses. Clay and sand were mixed together with stones and boulders transported by the ice from the Scandinavian mountains. This chalk-rich mixture of stone, gravel, sand, and clay - called moraine soil - covers the vast majority of Fyn County. The remainder of the County is covered by more homogenous deposits of sand and clay (Figure 1.2).

The ice advanced and retreated three times over Denmark and Fyn. On the last occasion the ice masses gouged the areas now occupied by the Great Belt and Little Belt and the rest of the coastal waters around Fyn. The moving ice pushed up material along its edges forming moraines, often as a series of crescent-shaped hills. The hills of Egebjerg Bakker and Svanninge Bakker in southern Fyn were formed in this way. The most common features in the landscape are moraine flats covered with moraine clay that was deposited under the ice masses as they advanced. Meltwater flowing from the ice formed small meltwater valleys, such as the river valley in which Fyns largest river, Odense Å, now flows, following a course essentially the same as the path carved by meltwater. In some places the meltwater formed deltas rather than valleys. At such locations, for example to the southeast of the City of Odense, flat heaths formed. In some places the meltwater flowed underneath the ice and carved trenches. Many of the current streams on Fyn run in such sub-glacial trenches. The trenches could also be filled by sand and gravel, carried by meltwater, to form ridges. These are often seen as extensions of the trench valley and may occur as a row of roughly parallel ridges.

The retreating ice masses left behind scattered blocks of ice. When this so-called "dead ice" melted, characteristic flat hills of layered clay were formed via sedimentation in a meltwater lake. Such formations are prevalent in 'High Fyn' (the area around the town of Vissenbjerg) in central Fyn. This landscape of small, rounded, and somewhat randomly-spaced hills, is a characteristic of the landscape of Fyn.

Since the end of the last ice age natural forces have changed the landscape of Fyn. The South Fyn Archipelago, which was above sea level at the end of the last ice age, was formed some 8 000 years ago by rising sea level. Subsequently, Fyn, and the rest of Denmark, began to tip along a line stretching from Strib in the west to Lohals in the east. Since the Stone Age, northern Fyn has risen by about one meter while southern Fyn, and the South Fyn Archipelago in particular, have sunk by more than three metres. At the same time, lakes have accumulated sediments or even become completely overgrown, and streams have cut into the landscape. Likewise, wave action has eroded and reformed the coastline, with cliffs forming where erosion occurred. An example of such changes is the small island of Vresen at the east coast of Fyn. In the 1600s it was a high moraine hill and populated; today it is reduced to a sand bank covered by high tides. In other locations material has been deposited as coastal banks. These banks have gradually formed into curved spits and, at some locations, led to the formation of lagoons.

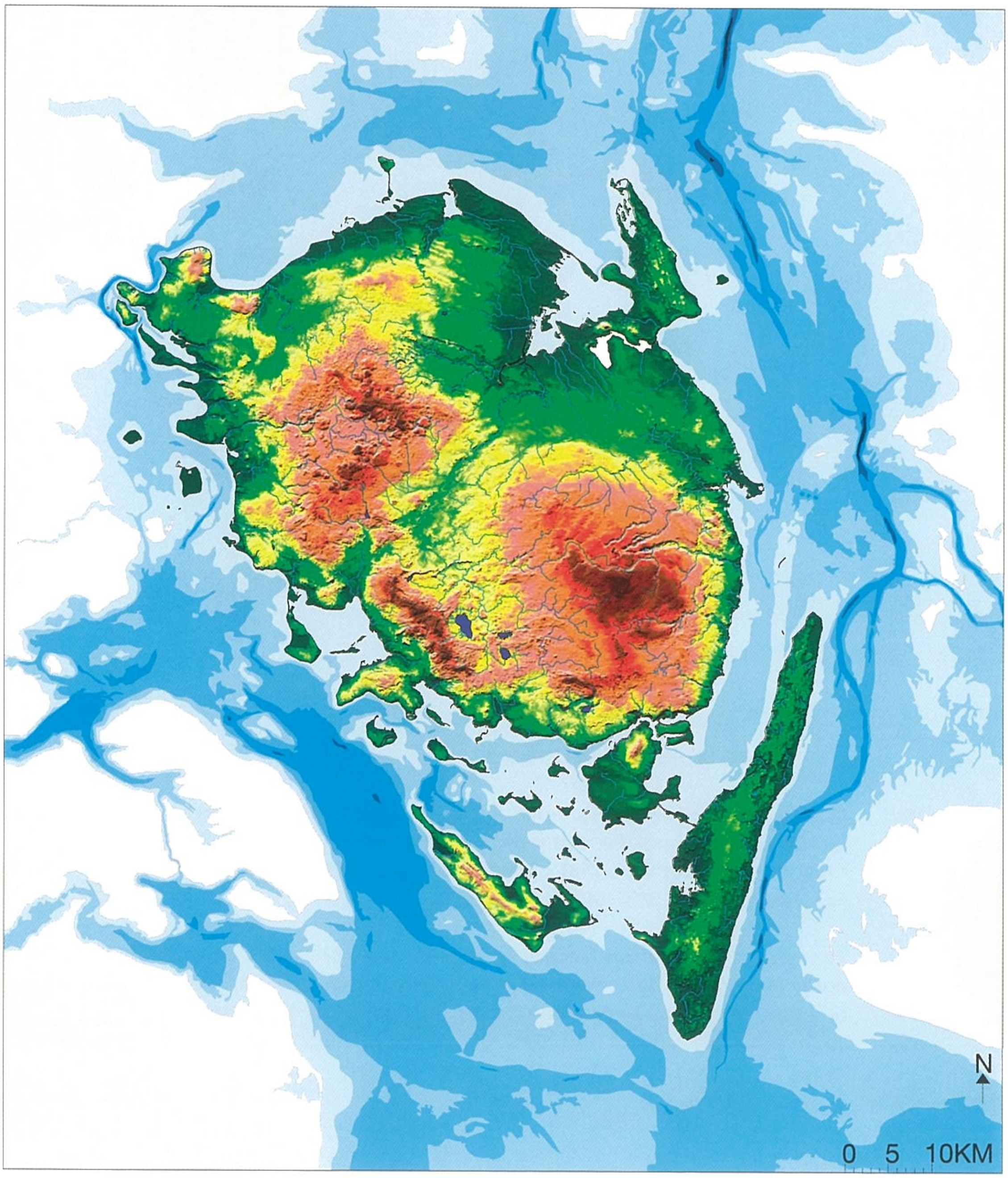


Figure 1.1
Topography of Fyn County and depths of its coastal waters. Sources: National Survey and Cadastre Denmark & Fyn County Council.

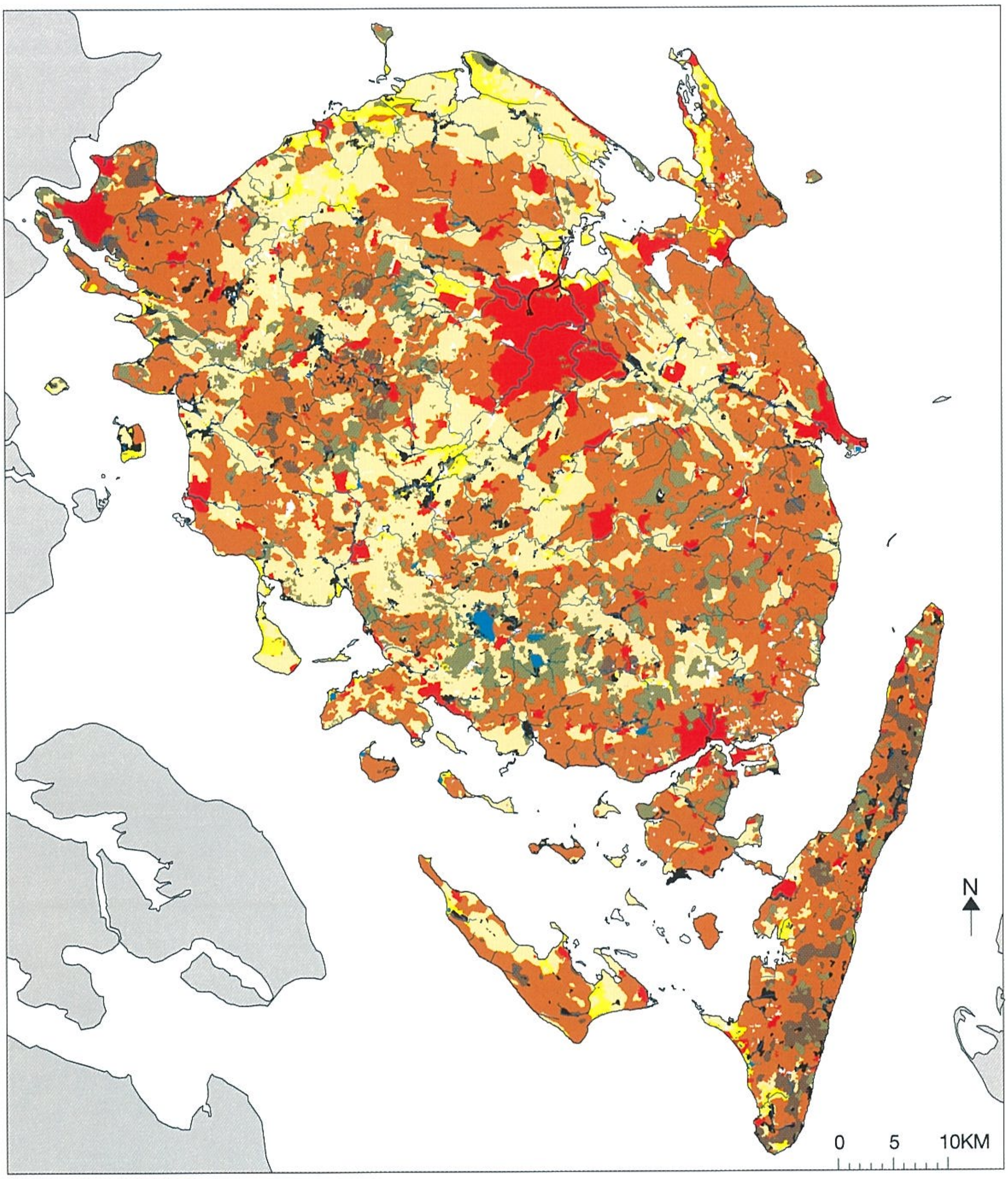
Figure 1.2
Soil types in Fyn County. The figure shows dominant soil types at 1 m depth. The soil on which urban areas and forests are located is not classified. Mapping undertaken by The Danish Institute of Plant and Soil Science, 1975-1979.

Legend

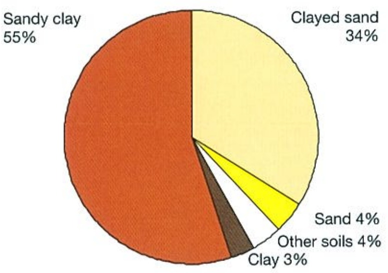
- Coarse/fine sandy soil
- Clayey sand
- Sandy clay
- Clay
- Special soils
- Humose soils

Un-classified:

- Urban areas
- Forests
- Freshwater bodies (lakes, streams)
- Residual areas



Soil types in Fyn County



Proportions of soil types in Fyn County

Clayey soils predominate, accounting for roughly 60% of the classified area. Sandy soils account for some 38% of the classified land. The County's soil is, thus, much richer than that of Denmark as a whole, for which clayey soils only account for some 30% of the total area.

The moraine soil in the County is ideal for the cultivation of crops. As a result, agriculture has left its mark on most of the landscape. Deep ploughing, liming, and other activities have made the surface soil more homogeneous.

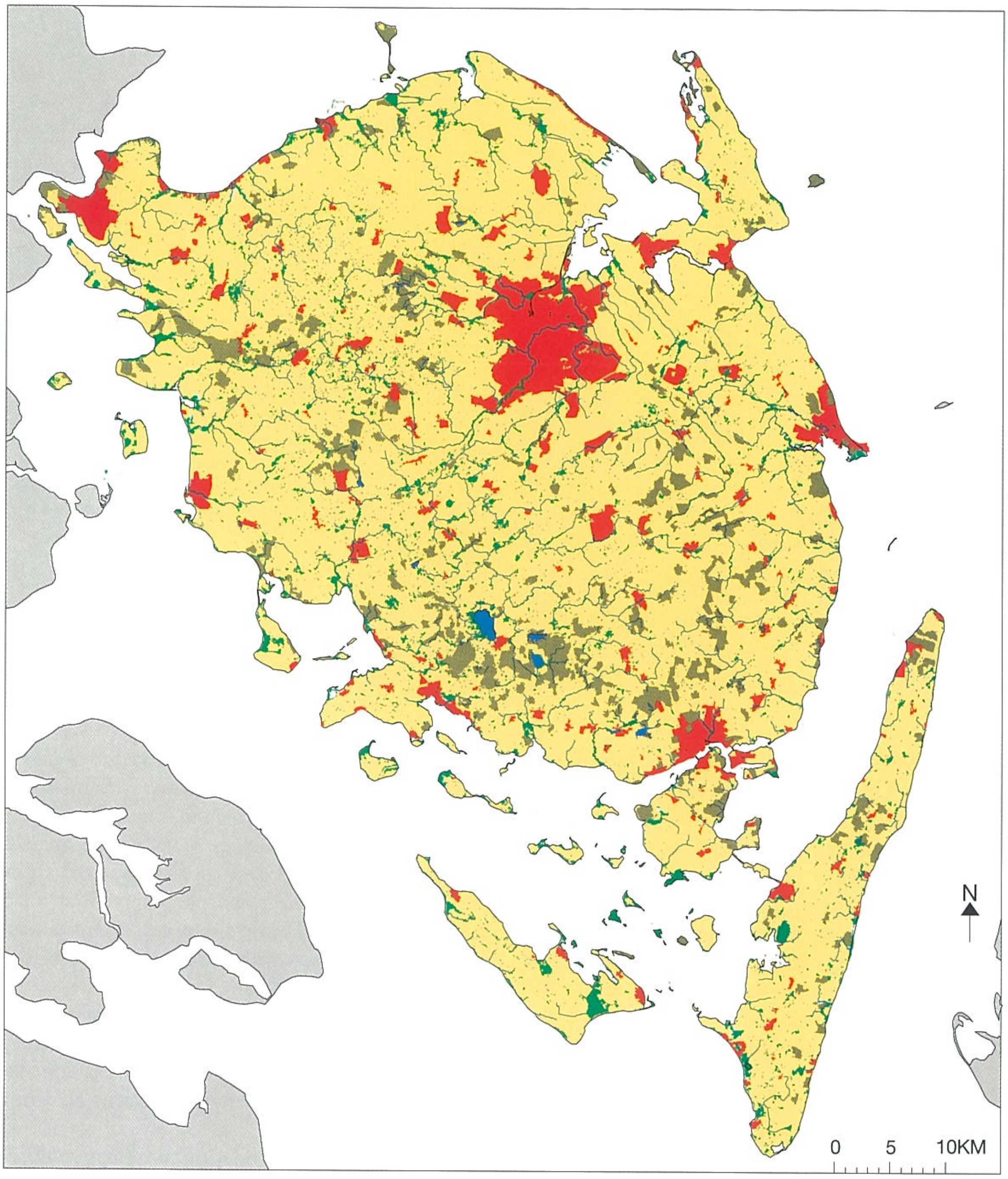


Figure 1.3
Land use in Fyn County, determined on the basis of the nationwide CORINE mapping by The Danish Institute of Plant and Soil Science, and habitat registration made by Fyn County Council in 1992.

Legend

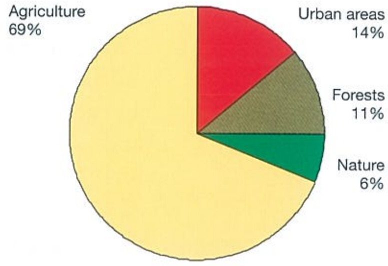
- Urban areas
- Agriculture
- Forests
- Freshwater bodies (lakes, streams)
- Nature (fens, meadows, salt marshes)

Fyn County	km²
Agriculture	2 406
Urban areas	488
Forests	383
Nature	209
Total	3 486

Land use in Fyn County - 1992

Land use in the County, as in the rest of Denmark, is dominated by agriculture. The proportion that is farmed is a little above the national average.

The extent of agricultural activities is reflected in the relatively small proportion of natural areas. They account for only 6.2% of the area compared with the national average of 9.6% (Danish Forest and Nature Agency, 1995). The term natural area includes lakes, meadows, commons, fens, moors, and salt marshes that are registered in accordance with the Nature Protection Act.



Land use in Fyn County

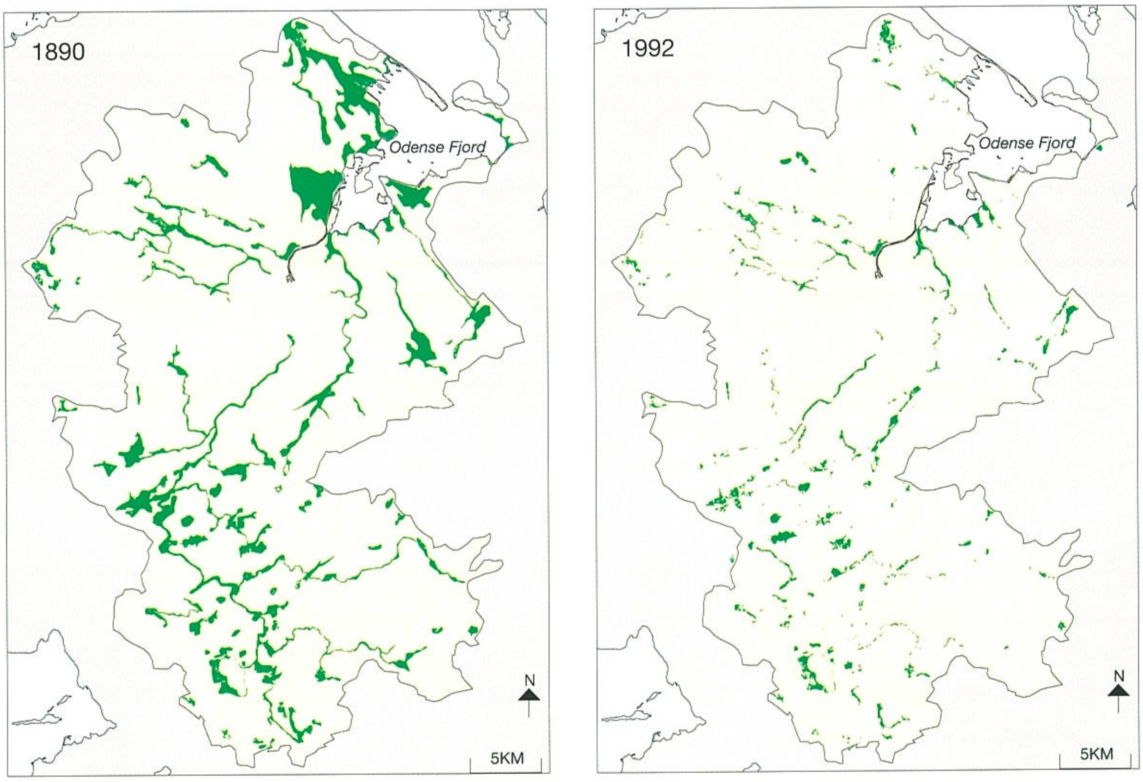


Figure 1.4
Extent of water meadows, fens, moors, and salt marshes in the catchment of Odense Fjord in 1890 and 1992. Produced by Fyn County Council using information from Ordnance topographical map (1:20 000) of 1890 and the Geodetic Institute's map (1:25 000) of 1992. Watercourses are not shown.

Odense Fjord catchment
Fens and meadows

The diversity of the topography of Fyn County (Figure 1.1) is reflected in the paths and descents of its streams. The slope of these vary from less than 0.3‰ to more than 5‰. Some watercourses have only a low gradient in their upper reaches, then descend rapidly as they approach the coast. The slope and size of watercourses determine, to a large extent, the types of plants and animals that live in them. The next section describes how human activities have affected the aquatic environment in and around the County.

Effects of human activities: a historical review

The aquatic environment is affected by numerous and diverse human activities. Many of these result in the loss of pollutants which enter the aquatic environment via riverine runoff or by atmospheric deposition.

In addition, many watercourses, shallow lakes, and fjords have undergone considerable physical changes or disappeared completely as a result of land reclamation for agricultural purposes etc. during the last hundred years.

Physical changes to waterbodies and wetlands have important implications for environmental conditions in the remaining aquatic environment. The "reclamation" of waterbodies, water meadows, fens, and moors to provide agricultural land has meant that the natural 'cleansing' capacity of such areas has been considerably reduced, resulting in an increased flow of nutrients to lakes, fjords, and other surface waters. Urbanisation and industrial development in towns and rural areas have also had consequences for the quality of aquatic habitats. Large areas have been built on or covered with asphalt, supplemented with sewerage networks and rain water drainage systems. Today approx. 14% of the land area of the County has been built on.

Human activities in the catchment of a water body are of primary importance in determining the degree of pollution of its habitats, and demanding implementation of measures to limit pollution.

A number of factors relating to human, cultural and social development that have had implications for the aquatic environment in and around Fyn County are examined below.

Disappearance of natural areas

The landscape of Fyn County is highly impacted by human activities (Figure 1.3). Roughly 69% of the County's area is farmed. Only some 6% can be termed 'natural', comprising lakes, meadows, commons, fens, moors, and salt marshes, although these areas make up a much higher part (23%) in river valleys within a 50 m zone along watercourses, and along the coastline.

In the last hundred years many larger natural areas have disappeared. For example, roughly 72% of the large water meadows, fens, moors and salt marshes in the catchment of Odense Fjord have disappeared (Figure 1.4). The primary rea-

Odense Å at Brobyværk near the village of Broby. The main photograph shows an unregulated section and the insert a regulated section of the river. In the regulated section the river's course has been straightened and the water meadows to either side drained, so that the land is farmed right up to the river bank. In the unregulated section the river twists naturally through the river valley with larger areas of water meadows and fens to either side.

Photos: Jan Koefod Winther, Fyn County Council

son for this decline is the richness of the County's soil, which makes it highly suitable for farming.

Land reclamation reduces the extent and quality of natural streams

During the last hundred years the extent of open watercourses in the County has decreased dramatically due to the piping of streams and ditches, and as a result of the regulation of watercourses, which has straightened and shortened them. On the basis of old maps it has been determined that the length of open watercourses in the catchment of Hundstrup Å on southern Fyn decreased from 174 km in 1890 to 97 km in 1992.

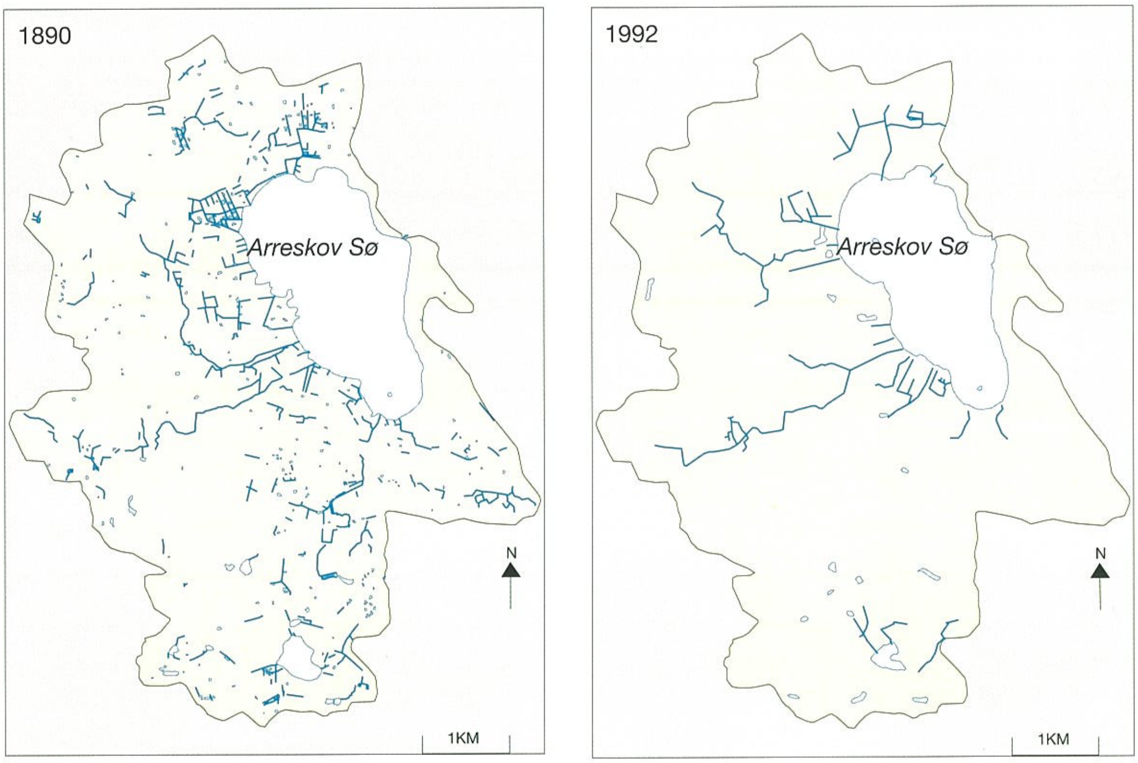
Furthermore, the quality of the natural environment in the streams and their valleys has declined significantly. Thus, 46% of the largest streams have been regulated (straightened, deepened etc.), and this figure appears to be even higher for smaller streams. The result is watercourses of a more sandy and homogenous character, and which are poor habitats for plants and animals. The majority of stream regulations were carried out during the last hundred years. The work was undertaken in partnership with land reclamation schemes, which drained land and built pump houses, with the aim of improving the amount and quality of arable land and so increase agricultural production. Today there are roughly 3 400 km of open watercourses, 60% of these being protected from physical changes by the Nature Protection Act since 1984.

Figure 1.5
Changes in watercourses and lakes in the catchment of Arreskov Sø between 1890-1990. Compiled by the Fyn County Council using information from the Ordnance topographical map (1:20 000) of 1890 and the Geodetic Institute's maps (1:25 000) of 1950 and 1992.

	Lakes (no.)	Streams km
1890	276	51.9
1950	117	32.7
1992	65	29.2

☐ Catchment

— Open water course



Land reclamation in stream valleys increases agricultural impact on the environment

The efficient drainage and reclamation of low-lying land in stream valleys have increased the amount of land available for intensive farming. At the same time, it has resulted in a reduction in the capacity of such areas to function as 'filters' of nutrients leaching from intensively farmed agricultural land to watercourses. As a result, watercourses, and the lakes and fjords into which they drain, are subject to greater pollution from agriculture.

Disappearance of shallow lakes and fjords

Reclamation of wetlands etc. for farming has also had serious implications for the lakes and fjords in Fyn County. Land reclamation involving the establishment of dikes and pumping facilities has resulted in the loss of numerous shallow fjords. This trend has been particularly evident during the last hundred years (Figure 1.4 and 1.5). Thus, the number of small lakes and ponds has decreased from 276 to 65 in the catchment of Arreskov Sø (Figure 1.5). This trend has greatly reduced the habitats of many wild plants and animals.

Watermills and flooding of water meadows affect stream organisms

Over time, many watercourses have been dammed for different purposes. As a result of the relatively large slope of many of its streams, the County has many watermills, some dating back to 1135. The mills were used to grind corn. Today there are only 17 functioning watermills limited to a handful of streams. The majority now produce electricity. Dams to enable the watering of meadows were used at many locations, especially during the 1800s. The aim of this practice was to fertilise the land and so increase production of hay and grass fed to livestock. Only traces of these earthworks remain today.

Dams and the piping of watercourses hinder the migration of aquatic animals, not least young eels ascending watercourses and sea trout returning from the sea to spawn. There are 219 known obstructions in the larger streams and an unknown number in the smaller ones. At the end of 1999, Fyn County Council had taken measures to allow the passage of aquatic animals at roughly 70% of these obstructions in larger streams (Figure 6.4), whereas similar action remains to be taken in smaller streams.

Management of watercourses should also benefit the environment

Different requirements for and uses of watercourses resulted in the first Danish Watercourse Act in 1880. The Act has subsequently been amended on numerous occasions, but up until 1982 was only concerned with ensuring the most efficient drainage of the land with regard to farming.

In 1982, the Act was changed to consider also environmental issues associated with watercourses. This necessitated the introduction of new regulations for the management of public watercourses. For example, weed cutting should not be so extensive as previously, when all vegetation was removed at least once a year. The regulations are set out in so-called 'stream directives'.

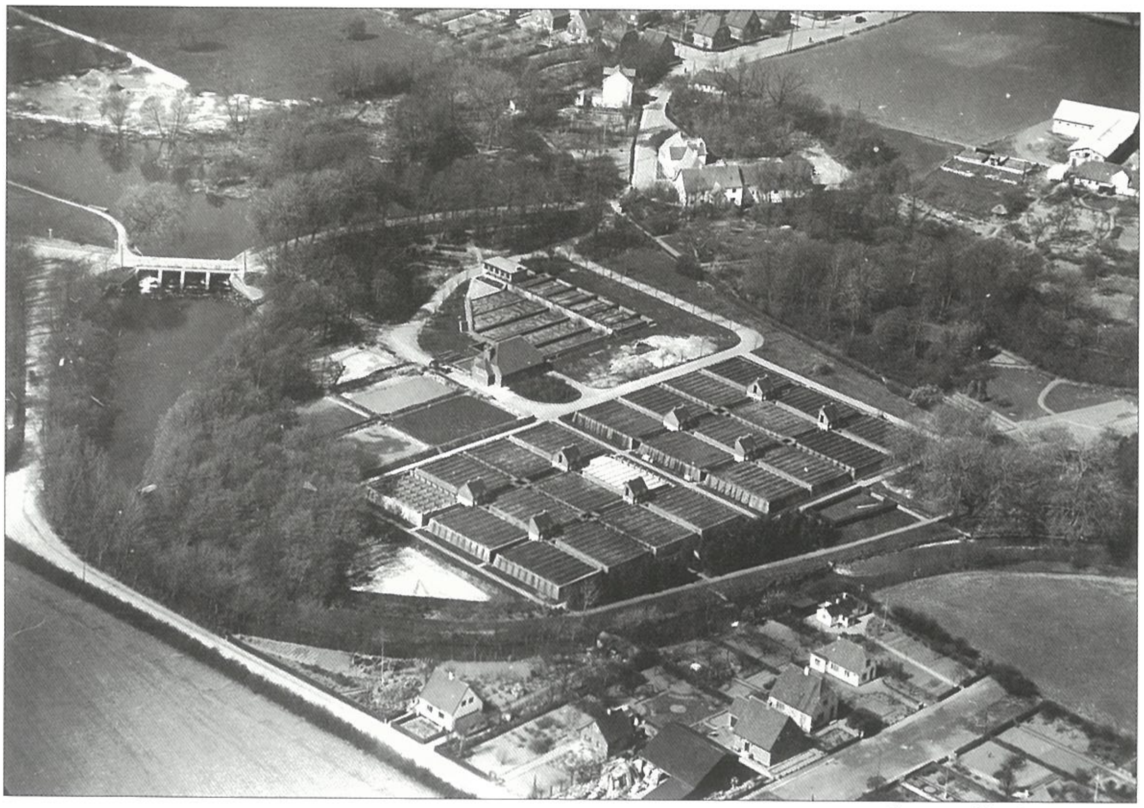
Of the County's open watercourses, 17% (primarily the larger ones) are managed by the County Council, 28% by the municipalities, and the remainder (private watercourses) by landowners. The County completed enacting the their stream directives in 1992. As of mid 2000, only 2 of the County's 32 municipalities had not adopted the more environmentally-friendly watercourse management. In the watercourses managed by Fyn County, the new management has resulted in significant changes to both plant and animal life. Thus, trout populations have increased at least fourfold, partly due to the increased number of hiding places (provided by the greater abundance of aquatic plants) (Wiberg-Larsen et al., 1994).

Wastewater treatment during the last century

The effect of human activities on the County's waterbodies includes their widespread use as natural sewers. At the beginning of the 1900s, poorly treated wastewater was released into watercourses from towns, dairies, slaughterhouses, etc. At that time flushing toilets were introduced in larger towns, which improved hygiene in the towns but resulted in increased loading of watercourses.

Flushing toilets were first introduced in rural areas in the 1950s, and here too resulted in the discharge of wastewater to watercourses and lakes. At this point agriculture also began to seriously pollute watercourses with discharges of silage juices, liquid manure, and juices from manure piles. Later, many dairies and slaughterhouses were closed due to centralisation, and effective measures for treating municipal wastewater were introduced. These actions resulted in a decrease in the pollution of watercourses. However, the greatest improvements in the treatment of wastewater occurred during the 1980s and beginning of the 1990s, especially regarding wastewater from towns and industry, and an end to illegal agricultural discharges of silage juices, liquid manure, etc. (see Chapter 5).

The first large biological wastewater treatment plants in Denmark were constructed during 1910-1920. Ejby Mølle, the largest treatment plant in Fyn County, and with a discharge to Odense Å, was one of these pioneering facilities. The facility began functioning as a mechanical treatment plant in 1908, and already in 1914-1917 was modernised to perform biological treatment.



Ejby Mølle wastewater treatment plant, in the City of Odense, as of 1938.

Photo: Loaned by Odense Waterworks

Trends in agricultural practices 1955-1999

The reclamation of wetlands (water meadows, fens, moors) in order to provide farmland is not the only manner in which agriculture has had an impact on nature and the aquatic environment during the last century. Several other factors relating to the development of agriculture and changing agricultural practises have been of major importance, particularly with respect to developments since the 1950s.

Farms have become specialised and livestock concentrated

Since the 1950s, agricultural production on Danish farms has become more concentrated and more specialised. Thus, the number of farms has decreased, and the farms that remain are larger and increasingly convert from a mix of crop and livestock farming to being specialised in production of cattle, pigs, or crops.

In Fyn County, the number of farms has decreased by 75% from roughly 21 800 properties in 1955 to roughly 5 300 in 1999. In 1955 livestock were present on almost all farms. Today livestock are only found on 62% of farms.

During the same period the size of farms has increased markedly, especially since 1970. The average farm size increased from 12 hectares in 1955 to 42 ha in 1999. From the 1950s to the end of the 1980s the number of livestock (expressed as animal units, AUs) in the County fell by roughly 35%, due solely to a decrease in the cattle population. The number of cattle nearly halved during this period; in contrast the number of pigs doubled (Figure 1.6).

Since the end of the 1980s the livestock population in the County has increased from some 174 000 AU in 1988 to about 195 000 AU in 1999. Thus, the production of pigs has increased markedly (40%), whereas the number of cattle has fallen by 15%. Compared to the 1950s, the present-day distribution of livestock is very uneven. In 1995, 75% of the County's livestock population was found on only 30% of its farms. Pigs, in particular, are now concentrated in great numbers on relatively few farms. As a consequence

What is an animal unit?

An animal unit (AU) is a unit of calculation, equivalent to a set amount of manure, and determined by its content of nitrogen. For each type of livestock the number of animals which annually produce this particular amount of fertiliser is calculated. Clearly, this number depends on the type of animal considered.

The nutrient content of manure from a particular type of livestock can vary with time as a result of changes in the composition of fodder etc.

As of the year 2002, 1 AU is set to be equivalent to 100 kg nitrogen in manure, and includes the amounts of nutrients produced by animals in the stall as well as outdoors. Thus, the loss of nutrients to the environment from manure in livestock stalls (e.g. by evaporation of ammonia etc.) is subtracted.

Currently (1997), this standard figure does not necessarily apply to all types of livestock. For example, 1 AU for porker is currently equivalent to 82 kg N/year, while 1 AU for large races of dairy cattle is equivalent to 102 kg N/year.

Examples of animal units (AUs)

Livestock type (1 AU)	Nutrient content (approx.) in manure (produced in stalls as well as outdoors)
1 dairy cow (large race)	102 kg N and 20 kg P per year
3 sows with piglets (removed after 4 weeks)	100 kg N and 33 kg P per year
30 porker	82 kg N and 21 kg P per year
80 sheep with lambs	150 kg N and 32 kg P per year

Sources: Poulsen & Kristensen (1997); Ministry of Environment and Energy (1998).

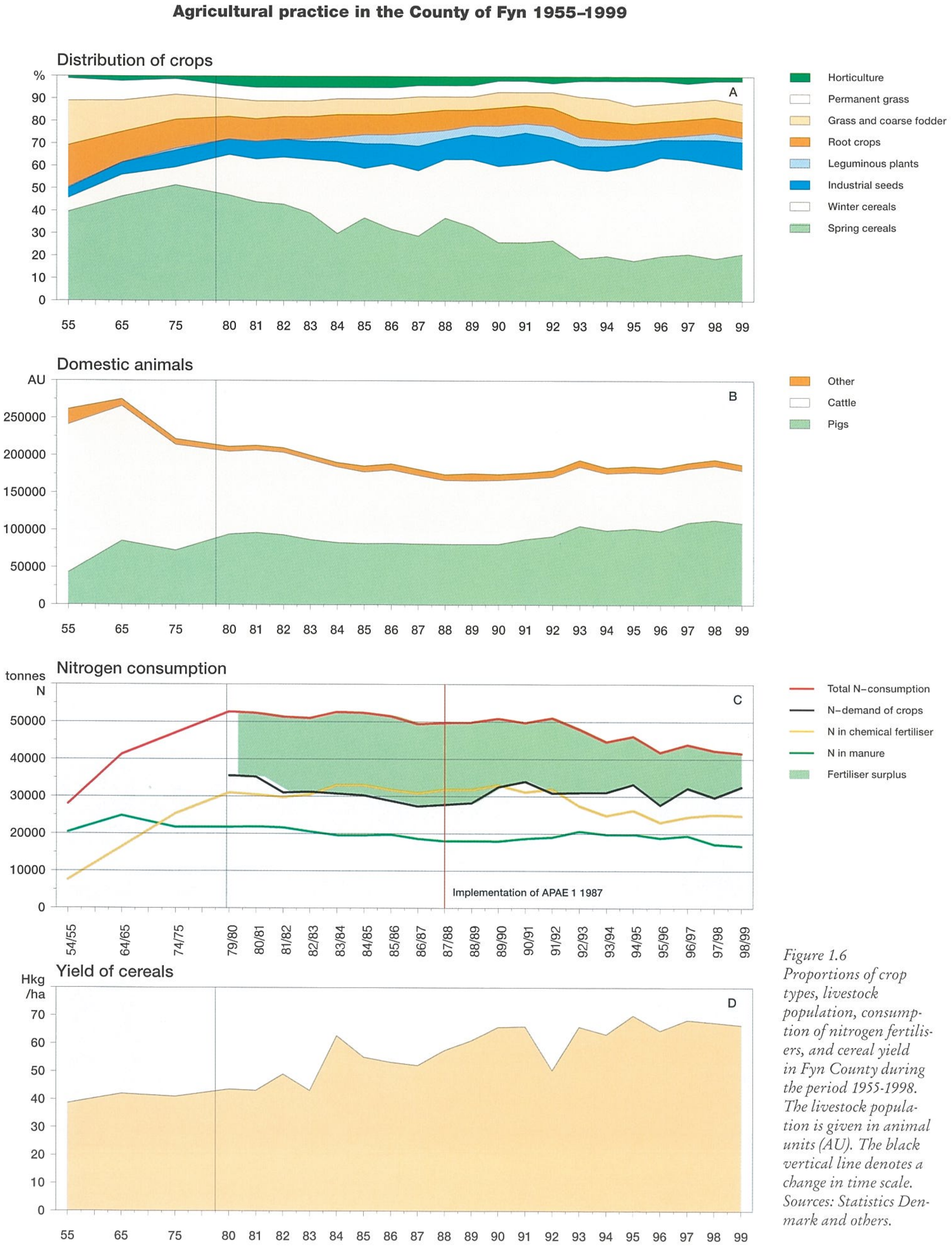


Figure 1.6
Proportions of crop types, livestock population, consumption of nitrogen fertilisers, and cereal yield in Fyn County during the period 1955-1998. The livestock population is given in animal units (AU). The black vertical line denotes a change in time scale. Sources: Statistics Denmark and others.

1950s hay bailer.

Photo: Nordfoto/Ulf Nielsen/STF

Harvesting on Bramstrup Estate in 1998.

Photo: Bjarne Andresen, Fyn County Coucil of these high livestock densities the accumulation of manure, and its subsequent spreading in the environment, have been concentrated on a much smaller area than before. However, new legislation adopted in recent years for the utilisation of manure mean that it once again has to be spread over a larger area. In 1999, the density of livestock on livestock farms in the County was 1.35 AU/ha, equal to the national average. However, if the total area of agricultural land in the County is considered, a figure of 0.87 AU/ha can be calculated for 1999.

Cereal crops now dominate

In 1955, the distribution of crops was influenced by mixed animal and crop farming, roughly half of a farm's land being used for growing grass and other forms of fodder. Cereals, almost exclusively being spring cereals, were grown on 45% of the cultivated land. By the mid 1970s the area of pasture in the County had roughly halved, while the area on which cereals were grown had increased to 60%. The situation is essentially unchanged today. Since the beginning of the 1980s, farming of winter cereals became increasingly popular, such that the area of these crops more than doubled between 1980-1999, while the area of spring cereals decreased correspondingly. In 1999, winter cereals were grown on roughly 62% of the land used for corn production. Concurrently, the area of pasture and fodder crops decreased by about 65% between the 1950s and the beginning of the 1990s. The increasing prevalence of cereal crops at the expense of the area of pasture and fodder crops has increased the risk of leaching of nutrients, as the long growing season of grass and green fodder crops makes them better to retain nitrogen than cereal crops.

Trends in the consumption of nitrogen fertilisers

In the 1950s, manure was the primary form of fertiliser applied to fields in Fyn County. In 1955, nitrogen and phosphorus in animal fertiliser accounted for more than 75% and 65%, respectively, of the total consumption of nitrogen and phosphorus. However, from the 1950s to the beginning of the 1980s the amount of nitrogen applied to fields increased by some 85%, from roughly 28 000 tonnes of nitrogen in 1955 to 52 000 tonnes in 1980. This increase was primarily a result of the increased use of artificial fertilisers. From the beginning of the 1980s to the beginning of the 1990s a roughly constant amount - a total of approx. 50 000 tonnes of nitrogen - was used annually.

When the amount of nitrogen applied to fields is calculated on an area basis, application increased from roughly 106 kg N/ha in 1955 to roughly 220 kg N/ha by the beginning of the 1990s. Since 1992, however, the consumption of nitrogen has fallen, partly as a result of the implementation of environmental protection measures. These are discussed in more detail in Chapter 5.

The total nitrogen requirements (i.e. economically optimal requirement) of crops was met solely by artificial fertilisers in the period from the late 1970s to the beginning of the 1990s (Figure 1.6). Manure was applied as well, but without taking its nutrient value into account. First in 1992/93 did the consumption of artificial fertilisers fall to a level below the nitrogen requirements of crops, indicating that greater value was being attached to the nitrogen present in animal fertiliser. As discussed in Chapter 5, the use of nitrogen fertilisers is a key factor with respect to the pollution load placed on the marine environment. The trend of increased consumption of fertilisers in the period up until the early 1980s, and the continued high level of consumption, have resulted in a considerable increase in pollution of the County's coastal waters during the last 40-50 years.

Trends in the consumption of phosphorus fertilisers

The use of phosphorus fertilisers has also increased during the last 40-50 years. Here developments at a national level over the last 15 years are considered.

The total amount of phosphorus fertiliser applied to fields during the period 1985-1998 decreased from 34 kg P/ha in 1985 to 31 kg P/ha in 1998. The majority of the phosphorus applied to fields is in the form of manure (roughly 21 kg P/ha in 1998). During the same period, 17-21 kg P/ha was removed with the harvested crops. Thus, a considerable excess of phosphorus is applied to fields, though the excess has been reduced from roughly 15 kg P/ha in 1985 to 11 kg P/ha in 1998 (Grant et al., 1999). Thus, fields fertilised with manure have, in particular, received considerably more phosphorus than the requirements of crops grown on them. This long-term over-fertilisation may be a "ticking bomb" for the aquatic environment, for once the soils phosphorus-binding capacity is exceeded the excess phosphorus will be readily washed from fields.

Trends in the consumption of pesticides

Agriculture is the largest consumer of pesticides in Denmark, accounting for roughly 81% of the total amount of pesticides used in 1999 (DEPA, 2000a). Other consumers are the paint and lacquer industry and the households. There are no data on trends in the consumption of pesticides in Fyn County, as statistics are only available on

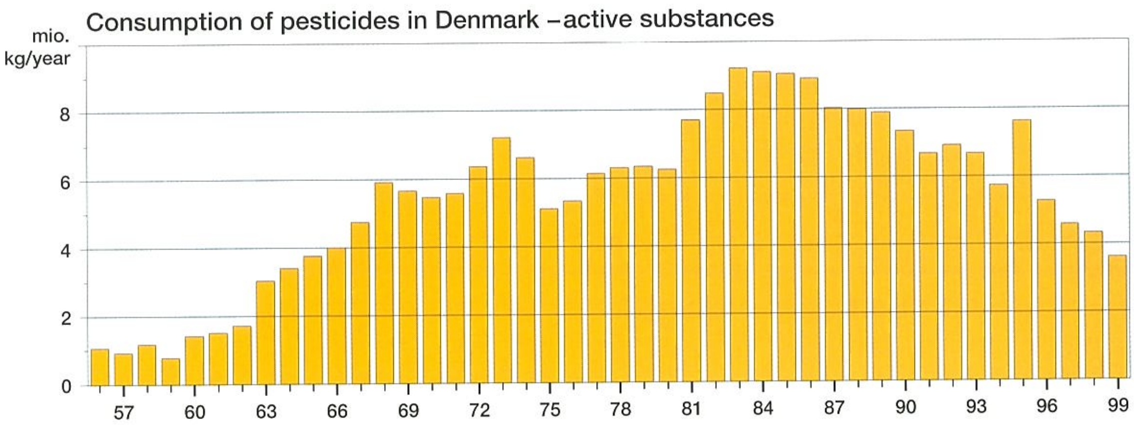


Figure 1.7
Total consumption of pesticides in Denmark during the period 1956-1999. Source: Danish Environmental Protection Agency & Geological Survey of Denmark and Greenland

a national basis (Figure 1.7). In 1997, the Danish Parliament voted to establish a commission to examine the overall consequences of a partial or complete ban on the use of pesticides. The commission was established in 1998 and presented a report in 1999 (Bichel Commission, 1999). The following citation on trends in the use of pesticides in agriculture is taken from the report:

"The use of pesticides in agriculture began to take hold after the Second World War. Initially, control of crop pests was of primary importance. With the development of new chemicals and better spraying equipment, the control of weeds by mechanical and manual methods was increasingly replaced by chemical control. The control of fungal diseases of crops also became increasingly common. The chemical regulation of plant growth (e.g. shortening of stalk length of cereals) has also gained a footing. Increased consumption of pesticides began, in all seriousness, at the beginning of the 1950s. From the mid 1950s to the beginning of the 1970s pesticide consumption increased five fold, so that in 1973 some 6.7 million kg of active compounds were used. After a fall in the mid 1970s, pesticide consumption increased to a new high of 7.5 million kg active compound in 1982/83, after which consumption fell to a stable level of around 3.7 million kg in 1997.

It should be noted, however, that while the consumption of pesticides has fallen, the effectiveness of their active compounds has increased. Thus, the actual treatment efficacy has decreased only slightly."

In 1999, 3.6 million kg of pesticide active substances were used in Denmark, representing an application to farmed fields of an average of 1.3 kg active substances per hectare, which, in turn, represents an average of 2.45 applications per year (DEPA, 2000b). The Bichel Commission has assessed that the average number of annual applications could be reduced to between 1.4 and 1.7 without significant expense for farmers or society.

Trends in crop yields

Already in the 1950s, yields from agricultural land in Fyn County were high in comparison with the standard at that time. Thus, the yields were generally higher than the national average. The significant increase in the consumption of fertilisers during subsequent years is reflected in increased yields, though the increase in yield has not occurred at the same rate as the increased fertiliser consumption (Figure 1.6). Thus, while the amount of fertiliser applied to a hectare of farmland increased by roughly 85% during 1955-1980, cereal yield increased by only approx. 10% (though protein content increased by roughly 45%). In addition, the use of higher-yielding strains of crops, improved farming methods, and increased consumption of pesticides have contributed to increase yields. During the period from the beginning of the 1980s to the beginning of the 1990s cereal yields in the County have increased markedly due to a significant increase in the area of farmland used for winter cereals and the use of new, high-yield strains.

Spraying of cereals.

Photo: Hans Meineche, Biofoto

Rubbish in a small pond.

Photo: Bert Wiklund

2 Environmental Planning

The regional plan

The Environmental Protection Act, enacted in 1974, was the first comprehensive act for protection of the environment. This act, together with the Planning Act, required each county in Denmark to produce a regional plan that included, among other things, mandatory guidelines concerning the use and protection of nature and the environment. The regional plans are required to respect existing legislation relating to nature and the environment, in particular the Nature Protection Act, the Watercourses Act and the Environmental Protection Act.

Fyn County Council's Regional Plan for the period 1997-2009 includes plans for watercourses, lakes and ponds, coastal waters, and groundwater. These plans set objectives for surface waters, describe their degree of pollution, and identify necessary actions to reduce pollution in order for the environmental quality objectives to be met. In Fyn County, groundwater is used to supply drinking water and other water needs, with surface water being used to a limited extent for irrigation. The Water Supply Act and the Planning Act require that the regional plan contains plans for the use and protection of drinking water resources.

The regional plans for the aquatic environment contain guidelines for the planning of wastewater treatment by the County's municipalities. They have resulted in a continuous modernisation of wastewater treatment facilities over the last 20-25 years. As of 1987, 1.6 billion Danish kroner had been invested in sewerage systems and wastewater treatment facilities in Fyn County.

In 1986, Fyn County Council passed an action plan for the modernisation of municipal wastewater treatment facilities, primarily in order to protect the most sensitive coastal habitats from discharges of nutrients (see Table 2.3). The plan required the investment of an additional 500 million Danish kroner and involved 59 treatment plants, all of which now meet the requirements of the action plan.

Table 2.1a
An overview of national and regional plans and reports for the aquatic environment 1985-2000 that set restrictions for land use (primarily agriculture). In addition, EC agricultural reforms are presented, as these to some extent address protection of the aquatic environment.

Action plans for the Aquatic Environment, adressing land use
1985: NPO Action Plan
· Stop discharges of leachate from manure piles and the like. (Harmony requirements: balance between the number of animals and agricultural land).
1986: Pesticides Action Plan
· 50% reduction in the amount of active agents used in1997, and halving in application frequency before 1997
1987: Action Plan for the Aquatic Environment I (APAE I)
· 50% and 80% reductions in runoff of nitrogen and phosphorus, respectively, before 1993
· Capacity to store nine months' production of manure, though with the opportunity for dispensation down to six months' capacity
· Obligatory plans for crop rotation and fertiliser management
· 65% of agricultural land farmed with green cover (e.g. grass, winter wheat) in autumn and winter
1989: Regional Plan for Forestation
1991: Action Plan for Sustainable Agriculture
· Deadline for meeting requirement for reduction of nitrogen runoff extended to 2000
· Obligatory fertiliser budgets for every farm
· Requirements for utilisation of manure and tightened rules for its storage and application
1992: European Community Agricultural Reform
· Identification of areas in which subsidies could be given to environmentally friendly farming practices (MVJ Agreement)
1994: 10-point plan to protect groundwater
· Including a ban on particularly environmentally harmful pesticides and further measures in order to achieve the goals of the Pesticides Action Plan 1986
1996: Tightening of the Action Plan for Sustainable Agriculture
· More rigorous requirements for the utilisation of manure, etc.
1997: European Community Agricultural Reform Agenda 2000 (Santer Plan)
1998: Drinking Water Committee's Report
· Management of water resources. Protection of groundwater via local action plans
1998: Action Plan for the Aquatic Environment II (APAE II)
· Extension, until 2003, of the requirement to meet the target for reduced runoff of nitrogen set in the APAE I
· Norm of fertiliser consumption to be reduced by 10%, with fines for exceeding the norm
· Improved utilisation of fodder and tighter animal density restrictions (maximum 1.4 (pig farms) to 1.7 (cattle farms) animal units/ha)
· Sharpened requirements for utilising the nitrogen in manure
· Requirement for catch crops on an additional 6% of the agricultural area
· Transition to organic farming on an additional 170 000 ha
· Establishment of 16 000 ha of wet meadows by the end of the year 2003
· Agreement on the introduction of environmentally friendly farming practices on 88 000 ha by the year 2003
· Planting of an additional 20 000 ha of forest by private persons and municipal authorities

continued over

Table 2.1a (continued).

1998:	Tightening of the Pesticide Action Plan
	· Increased taxation of pesticides
1999:	Bichel Committee's Report on the consequences of phasing out pesticides and transition to organic farming
1999:	Regional Plan Supplement on potential wet meadows according to the APAE II I
1999:	Departemental orders on additional regulations following legislation on environmental planning
	· Guidelines for the assessment of, among other things, the effect of livestock on the environment (VVM)

Table 2.1b An overview of national and regional plans and Departemental orders for the aquatic environment 1985-2000 concerning pollution loads from point sources, i.e. wastewater discharges and discharges from scattered homes.

Action Plans for the Aquatic Environment addressing wastewater discharges		
Regional		
1977:	Recipient Water Quality Plan, Fyn County Council	
1980:	Regional Plan 1980, Fyn County Council	
1983:	Revised Recipient Water Quality Plan, Fyn County Council	
1985:	Regional Plan 1985, Fyn County Council - incorporation of revised Recipient Water Quality Plan	
1986:	Action Plan for modernisation of municipal wastewater treatment facilities in Fyn County - Treatment requirements, as set out in Table 2.3	
1989:	Regional Plan 1989-2001, Fyn County Council - Action Plan incorporated in the Regional Plan	
1993:	Regional Plan 1993-2005, Fyn County Council - guidelines for treatment of wastewater from scattered homes	
1993:	Action Plan for treatment of wastewater from scattered homes in Fyn County	
1997:	Regional Plan 1997-2009, Fyn County Council	
2000:	Proposals for Regional Plan 2001-2013	
National		
1985:	NPO Action Plan	- Stop illegal discharges
1987:	Action Plan for the Aquatic Environment I	- Treatment requirements, as set out in Table 2.2
1997:	New national guidelines for managing wastewater in rural areas (revised wastewater management orders)	

Objectives for the quality of aquatic habitats (waterbodies and wetlands) in and around Fyn County, as set out in the Recipient Water Quality Plan in Fyn County Council's Regional Plan 1997-2009

Fyn County Council's Regional Plan includes the establishment of objectives for the quality of the County's coastal waters, lakes, and watercourses (see the recipient water quality map on the next page). The objectives are divided so as to impart various levels of protection. Areas covered by the most demanding objectives, such as scientific reference areas, should possess a natural and varied animal- and plant-life, and should be protected as much as possible from the effects of human activities. In areas covered by less-demanding objectives, a certain degree of human impact is acceptable, though such areas should still exhibit a natural and varied fauna and flora.

The Regional Plan 1997-2009 includes a number of sector plans that are presented in a total of eight main maps. The sector plans cover subjects such as urban growth, holiday, and leisure activities; nature, natural history, and natural resources; forestation; windmills; noise; the Recipient Quality Plan; the Wastewater Plan for Fyn; and groundwater. In 1999, Fyn County Council issued a supplement to the Regional Plan on selection of wetland areas to be established according to the Action Plan for the Aquatic Environment II.

Legend:

• • • • Border of municipalities

Streams:

Main runoff catchment borders

Runoff catchment borders for small streams

47 00 00 Runoff catchment numbers

Reference site for scientific studies

Site suitable for spawning and/or growth of salmonids

Site suitable for recreational and/or commercial fishing

Aesthetically satisfactory or if possible suitable for fishing

Aesthetically satisfactory

Reference site for scientific studies

Site suitable for recreational and/or commercial fishing

Coastal Waters:

Reference site for scientific studies

Coastal Waters should generally be suitable for recreational and/or commercial fishing, and where natural conditions are present, suitable for spawning and growth of fish

Beaches for bathing

Regional Plan 1997 - 2009

Objectives for Environmental Quality of Surface Waters

Fyns Amt

Table 2.2
The nationwide requirements of the Action Plan for the Aquatic Environment (1987) for treatment of wastewater at municipal facilities. The requirements are general and can be sharpened locally in consideration of sensitive water bodies. PE= Person equivalents (see p. 63 for definition).

Wastewater treatment facilities		APAE I - discharge limits		
	Capacity of facility, PE	Nitrogen, mg/l	Phosphorus, mg/l	BOD_5, mg/l
Existing facilities	<5 000	None set	None set	None set
	>5 000 og <15 000	None set	1.5	None set
	>15 000	8	1.5	15
New facilities	>5 000	8	1.5	15

Current legislation offers the opportunity for Denmark's counties to control pollution from towns and industry at a regional level, but gives only limited powers to control pollution from agriculture. Chapter 5, on sources of pollution, describes the reductions in pollution of the environment with nitrogen, phosphorus, and organic material that have been achieved partly by the introduction of the Regional Plan and partly as a result of national programmes.

The Regional Plan for 1997-2009 included objectives for a number of smaller watercourses for which objectives had not previously been set. This involves watercourses in 28 of the County's 32 municipalities. In addition, identification of areas of major importance with respect to drinking water resources, an activity initiated by the previous regional plan, was expanded. The proposed Regional Plan 2001-2013 identifies areas where groundwater intended to be abstracted for drinking water is sensitive to contamination by nitrate percolating from the ground surface. Detailed surveys in the coming years will identify areas for which special efforts, described in local action plans, will be required to protect drinking water resources from contamination by nitrate. With respect to the open land, the Regional Plan of 1993-2005 already stated that the handling of wastewater in rural areas should be improved. The Plan identified sensitive areas in which wastewater treatment should be to a standard equivalent to not less than biological treatment, and it set out recommended deadlines for the introduction of appropriate treatment (see Table 2.1b). The plan also aims to limit the discharge of wastewater from scattered homes within the catchment areas of many lakes and watercourses by the end of 2002.

National action plans for the aquatic environment

Concurrent with regional action plans, the Danish parliament has, since 1986, passed a series of national action plans for the aquatic environment (see Tables 2.1a and 2.1b). These plans set requirements for, among other things, reductions in diffuse discharges of nutrients from agricultural land (an overview of the most important measures is presented in Table 2.1a). These national plans set minimum reduction targets without particular consideration of the sensitivity of the individual water body. In contrast, the regional plans can sharpen requirements for the treatment of wastewater discharged to particularly sensitive areas (Table 2.2 and 2.3).

Chapter 5 discusses the fact that the objectives, set out in the Action Plan for the Aquatic Environment I (APAE I, 1987), of 50% and 80% reductions in the discharge of nitrogen and phosphorus, respectively, have not been achieved for diffuse losses from land use, whereas discharges from point sources, i.e. municipal sewage treatment plants and industry have, since 1991, largely met these goals. Consequently, the APAE II was enacted in 1998 with the aim of ensuring the desired reduction in diffuse losses of nutrients before 2003 (Iversen et al., 1998). The requirements

Table 2.3
Fyn County Council's Regional Action Plan (1986) requirements for treatment of wastewater at municipal facilities. All facilities with a capacity of more than 700 PE are required to remove phosphorus, and all facilities with a capacity of more than 3000 PE are required to remove both nitrogen and phosphorus. An asterisk indicates that the requirement was set with regard to a lake or fjord downstream of the discharge rather than with regard to the recipient watercourse.

Waterbodies			Fyn County - discharge limits		
	Nitrogen mg/l	Phosphorus mg/l	BOD_5 mg/l	Ammonia-N mg/l	Suspended material, mg/l
Watercourses	8 *	0.5/1/1.5 *	8/10	2 (summer) 4 (winter)	10/15
Sensitive marine areas	8	0.5/1	15	3	15
Less-sensitive waterbodies	8	1.5	15	3	20

of the APAE II should also help ensure that Denmark lives up to the 1991 European Community directive for reducing nitrogen pollution (Nitrate Directive, see Table 2.5).

International plans and requirements

Denmark has signed a number of international conventions for protecting marine environments, freshwater aquatic habitats, and wetlands (see Table 2.4).

Denmark aims to meet the requirements and recommendations for pollution control and monitoring of the aquatic environment set out in these conventions, not least HELCOM's Minister Declaration of 1998 of a 50% reduction in the discharge of nitrogen between 1985 and 1995, (recently postponed to 2005), by, among other means, the pollution control measures in the APAE I and II and the associated monitoring programme (Chapter 3). The latest version of this programme, which focuses to a greater degree on hazardous substances, should help to ensure that Denmark meets its international surveillance obligations.

In Fyn County, protection of aquatic habitats and wetlands as required by the Ramsar Convention is ensured via regional planning and administration of laws protecting nature and the environment.

The European Community also produces directives for the protection of various parts of aquatic environment as a whole (Table 2.5). These directives are mandatory for all member countries and must be incorporated in their national legislation.

Denmark has attempted to meet the requirements of those directives enacted to date via laws to protect nature and the environment, including legislation arising from the APAE I and II, and the enactment of regional plans. The Water Framework Directive will require a change in efforts with respect to planning, pollution surveillance, and pollution control in the aquatic environment.

The European Community Agricultural Reform of 1992 addresses the environment in the form of establishing a range of optional subsidy schemes for environmentally-friendly land uses. In recent years these schemes have, to a certain extent, contributed to protection of aquatic environment (see Chapter 5). The EC's Agricultural Reform of 1997, Agenda 2000 (the Santer Plan), also addresses protection of the aquatic environment. With a basis in the agricultural reform of 1992, Denmark has established a system of subsidies to environmentally-friendly land uses, where particularly sensitive agricultural areas are identified to be farmed with greater regard for the environment. Plans are also being drafted for afforestation, partly with the aim of protecting sensitive

International Conventions	Date of adoption
Ramsar Convention on protection of waterbodies and wetlands of international importance	1975
Helsinki Convention I and II (HELCOM) on protection of the Baltic Sea from land-based pollution, dumping, and off-shore activities	I: 1974 II: 2000
Bern Convention on protection of Europe's wild animals and plants	1979
Bonn Convention on protection of migrating species, including water birds and small whales	1979
OSPAR Convention on protection of the marine environment in the North East Atlantic from land-based pollution, dumping, and off-shore activities	1992
Biodiversity Convention on sustaining biological diversity (UNCED)	1992
Agenda 21, UN conference on sustainable development	1992
Copenhagen Agreement on control of oil pollution entered into by Denmark, Norway, Sweden, Finland, and Iceland	1993
North Sea Conference Ministers' Declaration, e.g. the Esbjerg Declaration 1995, stating initiative and recommendations to protect the marine environment in the North Sea, including the Danish Wadden Sea. The next (5th) conference is to be held in Norway in 2002	
FN protocol for reducing atmospheric pollution to control acidification, eutrophication, and ozone-related problems	1999

Table 2.4
An overview of international conventions, declarations, and other agreements on protection of the marine environment, other aquatic habitats and wetlands, and their animal- and plant life that Denmark has adopted or otherwise participates in.

groundwater supplies from contamination by intensive agricultural practices. The Reform also includes proposals for increasing the rate of transition from intensive farming to organic farming, though implementation of the Reform is left largely to the individual member states. In Denmark, the Bichel Committee, under the Ministry of Food, Agriculture and Fisheries, recently (1999) completed a thorough examination of the economy of Danish agriculture, including the

Table 2.5 European Community directives setting out guidelines for protection of the aquatic environment from discharges of hazardous substances, documentation obligations etc.

International Conventions	Date of issue
Quality requirements for surface water that may be used as drinking water (75/440/EEC)	1975
Bathing water directive on quality requirements for bathing waters (76/160/EEC)	1976
Water quality directive on limiting discharge of certain hazardous substances (76/464/EEC, amended by the directives 86/289, 88/347, and most recently 90/41515)	1976
Council's decision on common procedures for exchange of information on the quality of surface water (77/795/EEC, amended most recently by the Council's decision 86/574)	1977
Directive on titanium dioxide waste (78/176/EEC)	1978
Fishing water directive on protection of the freshwater habitats of fish (78/659/EEC, amended most recently by the inaugural act 1985)	1978
Shellfish directive on water quality requirements for shellfish (79/923/EEC)	1979
Bird protection directive on the protection of the habitats of certain bird species (79/409/EEC amended most recently by the directive 97/49/EC)	1979
Directive on methods of analysis and frequency of sampling for surface water used to supply drinking water (79/869/EEC)	1979
Groundwater directive on the protection of groundwater from certain hazardous substances (80/68/EEC)	1980
Drinking water directive on the protection of drinking water (80/778/EEC)	1980
Mercury directive I on the discharge of mercury from electrolysis of chloralkali (82/176/EEC)	1982
Cadmium directive on the discharge of cadmium (83/513/EEC)	1983
Mercury directive II on the discharge of mercury from other industrial activities (84/156/EEC)	1984
Directive on the discharge of hexachlorocyclohexane (84/491/EEC)	1984
IAA directive on assessing the impact on the environment of certain public and private projects (85/337/EEC, amended most recently by the directive 97/11/EC)	1985
Sewage sludge directive on protection of the environment from the application of sludge from wastewater treatment facilities (86/278/EEC)	1986
The European Environmental Agency (The Council's Order 1210/90, amended most recently by Council Order 993/99)	1990
Report directive on standardisation of documentation to be submitted as required by environmental directives (91/692/EEC and 95/337/EC)	1991
Nitrate directive on protection of water from pollution with nitrate from agriculture (91/676/EEC)	1991
Urban wastewater directive on sewerage systems and setting of cleansing requirements (91/271/EEC, amended most recently by the directive 98/15/EC)	1991
Habitat directive on the preservation of natural habitats, wild animals, and plants (92/43/EEC)	1992
Biodiversity directive. Council's decision on sustaining biological diversity (93/626/EEC)	1993
IPPC directive on integrated surveillance and control of pollution (96/61/EC)	1996
Atmosphere directive on emissions of sulphur, nitrogen oxides etc. (96/62/EC)	1996
Water framework directive on common guidelines for the EC's water policy (2000/60/EC)	2000
OECD/EUROSTAT: Requirement to submit key environmental data every second, even year	

possibility of transition to organic farming. The findings of the Committee will be included in Denmark's implementation of the EC's Agenda 2000. Denmark has also sent an application to the EC Commission for support of development in rural areas during the period 2000-2006 in accordance with the Council's Order no. 1257/1999. In a number of areas the application incorporates increased consideration of the environment via, for example, creation of waterbodies, afforestation, pesticide- and fertiliser-free buffer zones etc.

Integrated plans for protecting surface water, groundwater, and nature

As previously described, national and international action plans seek general protection of the aquatic environment and nature.

Current Danish legislation also allows wastewater treatment to be controlled on a regional basis, as the counties have the legal right to tighten general minimum requirements set out in national and international legislation. With regard to pollution with nutrients (nitrogen and phosphorus), pesticides etc. from agriculture, regulation of agricultural pollution to date has almost exclusively followed general, nationally-applicable environmental action plans adopted by the Danish State.

Regulations in the Planning Act, Environmental Protection Act, Environmental Impact Assessments, and the Animal Fertiliser Departmental Orders also give Denmark's counties and municipalities the possibility to regulate pollution of the environment by agriculture to a certain degree over and above the general regulations pertaining to agriculture's relationship with the environment, if this is considered necessary to meet politically-adopted quality objects for the aquatic environment.

Prerequisites for meeting objectives for Fyn County's lakes, coves, fjords, and coastal waters are that discharges of nitrogen and phosphorus are reduced by a minimum of 50% and 80%, respectively, as adopted in the APAE I and readvanced in the APAE II. Achievement of the national objectives will not necessarily mean that nutrient loading has been reduced sufficiently to allow quality objectives to be met in local waterbodies (lakes, fjords etc.) where, for example, the density of livestock (in the water body's catchment) is higher than the national average. The sensitivity of a local water body compared with the actual pollution load it receives can mean that measures to protect the environment required of, for example, agriculture in the catchment, must be tightened and/or limits on agricultural production set if the quality objectives adopted for the water body are to be met.

In the area of groundwater, recent legislation has been passed giving Denmark's counties the possibility to control agricultural practices in abstraction areas where groundwater is particularly sensitive to nitrate pollution. For these "areas of intervention with respect to nitrate" Denmark's counties are required to plan efforts for protecting groundwater, after which they have the possibility of placing restrictions on land use upon payment of compensation.

Meeting quality objectives in sensitive surface water areas and other natural areas for which general protection measures are not sufficient will, as for groundwater, require the implementation of specific action plans. These action plans should be integrated, so that protection of nature and the environment are dealt with together. The action plans should include all relevant pollutants from households, industry, and agriculture. An action plan produced for a watercourse catchment area would form a good basis for environmental protection in the catchment, and thus also offer a considerably greater degree of production control for both industry and agriculture, as businesses will know the environmental protection requirements they must meet for a number of years ahead.

Through the BERNET (Baltic Environmental Regional Network) project, comprising 7 regions around the Baltic Sea, Fyn County Council has initiated a comparative analysis of eutrophication management strategies in the particpating regions (BERNET, 2000a-h). The results of the analysis are the basis for developing regional action plans for each region, focused on achieving better environmental quality through integrated management strategies, according to the principles of integrated environmental assessment (IEA).

It would be appropriate to incorporate action plans in regional planning as part of the overall physical planning for a region. In addition, such action plans will harmonise with guidelines in the EC's Water Framework Directive.

"Liv II", Fyn County's surveillance vessel. *Photo: Fyn County*

3 Monitoring Programme

National and international laws require that Denmark can document the condition of the aquatic environment. Likewise, implementation of the regional and local plans and their administration requires knowledge of conditions in the aquatic environment. Consequently, monitoring programmes are an integral part of both the regional and national plans for the aquatic environment discussed in the previous chapter. Results from these programmes will be used to assess the condition of the aquatic environment, changes in conditions, and the effects of human activities on the aquatic environment.

Regional surveillance is planned and managed by Denmark's counties, though some aspects, e.g. collection of samples for monitoring the quality of bathing and drinking water, and discharges from municipal wastewater treatment plants, are carried out by the local municipalities, with the data passed on to the county authorities. Surveillance provides data that can be used as a basis to assess if objectives set for the aquatic environment are being met. The results can also be used to identify additional pollution control measures that should be implemented if objectives have not been met. Fyn County Council began surveillance of the aquatic environment already in the mid 1970s. Consequently, changes in the condition and degree of pollution in many surveillance areas can be assessed with the aid of long time-series data.

National surveillance, which is partly carried out to determine the effectiveness of the Action Plan for the Aquatic Environment I and II (APAE), is a cooperation between the Danish State and its counties. The first version of the programme was implemented in 1989, and revised for the first time in 1992. The surveillance programme of the APAE I, which ran until the end of 1997, is described by the Danish Environmental Protection Agency (DEPA, 1993). In 1998, the APAE I's surveillance programme was reviewed, and replaced by a new surveillance programme, NOVA 2003, the National Surveillance Programme for the Aquatic Environment (DEPA, 2000b). Fyn County Council, like the other counties in Denmark, has entered into an agreement with the Danish Environmental Protection Agency covering the period 1998-2003, in which increased emphasis will be placed on monitoring hazardous substances and the contribution of agriculture to pollution of the aquatic environment.

Results from the national monitoring programme are submitted annually to the relevant national scientific organisations and authorities. The surveillance shall "contribute to documenting the effect of measures introduced to improve the conditions in the aquatic environment. The results should contribute to forming a basis for deciding if additional measures to control pollution and the effects of other human activities on the aquatic environment should be implemented in order to meet quality objectives set for the aquatic environment" (DEPA, 2000b; c).

Both the national and regional surveillance include all aspects of the water cycle, and is carried out in an integrated manner by Fyn County. The extent of the surveillance activities carried out by Fyn County Council, divided into the national and regional programmes, is described in detail in the County Council's annual reports on surveillance of the aquatic environment. The primary activities in the NOVA 2003 monitoring programme are presented below.

Point-source discharges

Discharge of wastewater from municipal treatment plants, individual factories, and storm water overflows of wastewater from sewerage systems are described as point-source discharges. National and regional surveillance of such discharges is carried out jointly.

Wastewater discharges: In Fyn County, 34 wastewater facilities are covered by the APAE I's requirements for the treatment of wastewater (see Chapter 2). These facilities, and an additional 25 plants, have been upgraded to meet the requirements set out in Fyn County Council's Regional Plan.

The County Council inspects 82 facilities with a capacity of more than 30 PE (see Chapter 5). At the 60 largest facilities, the local municipalities and the County take six or more samples annually in order to give a statistical base to determine whether discharge criteria are being met. At the remaining 22 smaller facilities, adherence to requirements is assessed by single samples.

Wastewater samples are analysed for nitrogen, phosphorus, oxygen-consuming material, and suspended matter. At three facilities concentrations of hazardous substances (108 different chemicals in wastewater and 125 in sewage sludge) are measured according to the NOVA 2003 surveillance programme. In addition, heavy metals are analysed at 14 treatment plants and phenols at three facilities.

Stormwater discharge: Discharges from the County's estimated 1 715 stormwater outfalls are followed by calculating emissions of water and nutrients, and by an intensive monitoring programme at a single station in a combined sewerage/rainwater network in the town of Rynkeby. In addition, intensive measurements, including the continuous registration of oxygen and ammonia concentrations, are made at two stations in the river Odense Å, one upstream and one downstream of the City of Odense, with the aim of determining loading from the City's 68 stormwater outfalls.

Individual industrial discharges: 22 industries in Fyn County discharge wastewater directly to watercourses or coastal waters. Six of these industries discharge wastewater equivalent to more than 30 PE. Consequently, their discharges are monitored in the same manner as discharges from municipal wastewater facilities, as is required by the NOVA 2003 monitoring programme. The discharge from one of the six industries is also monitored for levels of heavy metals and hazardous substances.

Scattered houses: Some 29 000 houses in Fyn County are not connected to a wastewater treatment facility. The wastewater discharged by scattered houses, like that discharged by agriculture, is considered a diffuse source of pollution. Loading of water bodies by discharges from scattered houses is calculated by the County Council on the basis of data supplied by municipalities.

Land monitoring programme

Land surveillance involves monitoring the loss from agricultural land to the aquatic environment of nutrients, pesticides, and other substances harmful to the environment. At the same time, detailed information on farming methods is regularly collected, so that the relationship between agricultural practices and their effects on the environment can be better understood.

The NOVA 2003 monitoring programme includes 25 land surveillance catchments in Denmark, of which three are in Fyn County. A land surveillance catchment is an area of land (typically 5-50 km^2) in which agriculture is the predominant land use, and in which agricultural practices and their effects on the environment are monitored intensively. Compared with the previous programme, the land monitoring programme in NOVA 2003 is expanded so as to include more catchments, and there is greater emphasis on hazardous substances, primarily pesticides. In addition, there has been a strengthening of activities that can provide information on nutrient cycles, both at the farm level and at the hydrological level (at the level of the water cycle).

The land monitoring programme should be able to answer the question as to whether the national action plans to reduce loading of the environment by agriculture are working as intended: for example, if the objective for a 50% reduction in emissions of nitrogen to the aquatic environment has been met.

Land surveillance investigations in Fyn County are primarily made in the catchments of the rivers Odense Å and Hundstrup Å, and the stream Lillebækken. The catchment of Lillebækken is the most intensively studied, as measurements here are made

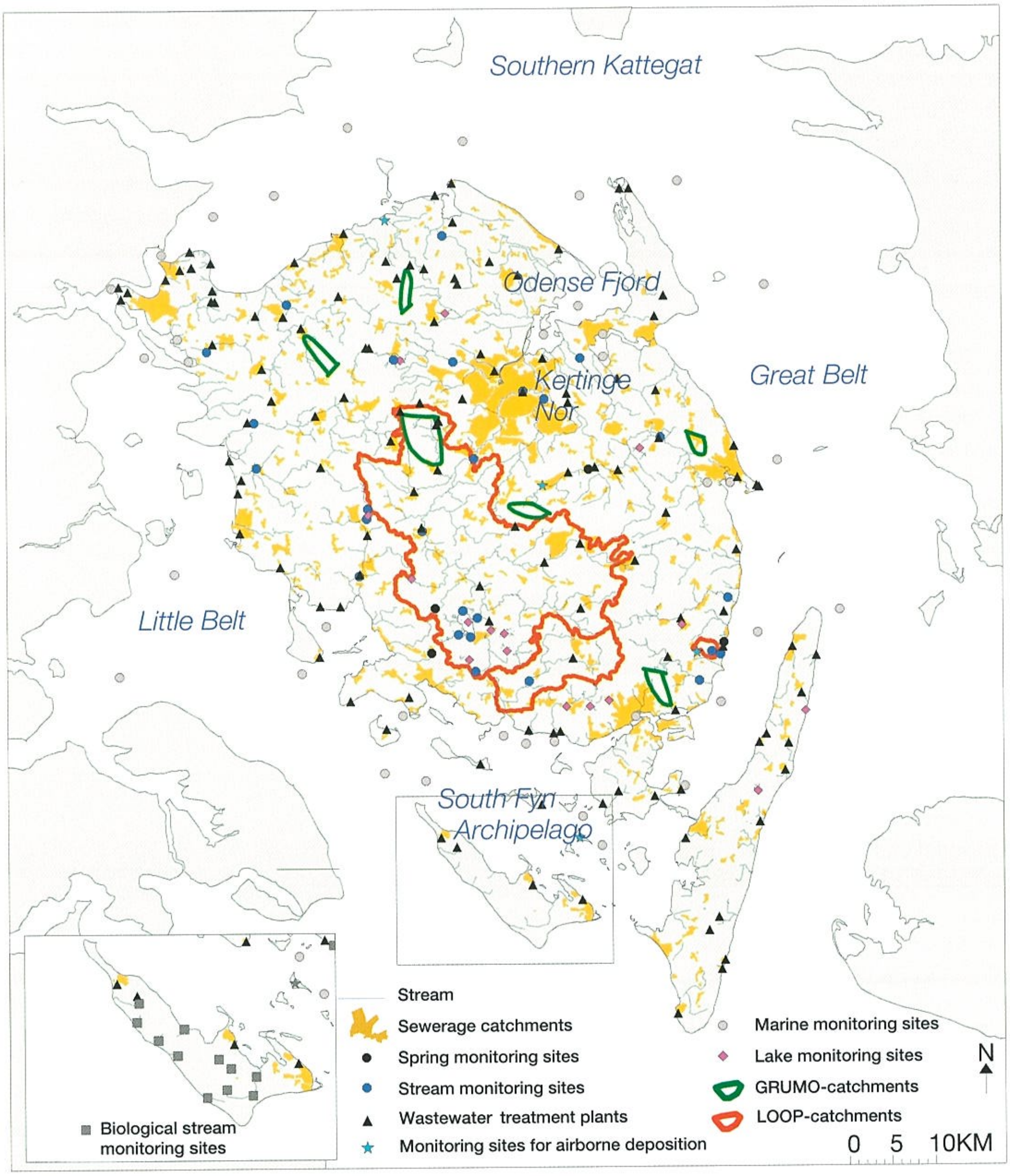


Figure 3.1
Selected parts of national and regional surveillance programmes in 1998, the first year of the NOVA 2003 surveillance programme. The map shows hydrographic/water chemistry sampling stations in coastal waters, and the lakes that were part of the NOVA programme or Fyn County Council's regional programme in 1998. Also shown are wastewater treatment plants that are monitored, the stations in watercourses and springs where physical/chemical measurements are
continued next page

of all parts of the water cycle: i.e. precipitation, soil water, drainage water, shallow and deep aquifers, and the watercourse. The surveillance results are compared with information collected on agricultural practices in the area. In addition, nutrient concentrations in the ploughed layer are measured, data on the physical structure of the soil is collected with the aim of producing advanced hydrodynamic models, and concentrations of harmful/hazardous substance in liquid manure are determined.

Agriculture is a so-called "diffuse" source of pollution. The total contribution of agriculture to loading of Fyn's aquatic environment is calculated using measurements of the transport of materials in watercourses, in wastewater discharges from point sources, and the background (natural) contribution of nutrients in watercourses, as determined in watercourses that alone drain forested and "natural" areas.

Watercourses and springs

Physical and chemical surveillance of watercourses allows description of the transport of water, nitrogen, phosphorus, and inorganic material, partly in order to assess water quality, and partly to allow calculation of the pollution loading from land to lakes and coastal waters. Measurements are made at 22 stations in 15 watercourses as part of the NOVA 2003 surveillance programme, and from an additional three stations as part of the County's regional programme. Four springs are also monitored. The presence of hazardous substances, notably pesticides, is measured in the river Odense Å, upstream of Ejby Mølle wastewater treatment plant. Pesticide analysis is also part of the land surveillance programmes in the catchments of the watercourses Lillebækken, Odense Å (at Kratholm), and Hundstrup Å.

Catchment analyses are made out in order to better understand the sources and routes of transport of water and nutrients. These analyses are made at, among other locations, the specific land surveillance areas in the catchments of the watercourses Odense Å, Hundstrup Å, and Lillebækken.

Biological surveillance of watercourses is carried out by registering the numbers of certain small aquatic animals (invertebrates) used to classify environmental conditions in watercourses. Under the NOVA 2003 monitoring programme, 104 stations have been selected in Fyn County. Seven of these are included in an expanded programme that includes documentation of conditions in the catchment area, and physical and biological conditions (plants, small animals, and fish) in the watercourse. One aim of this broadened surveillance is to determine the influence of wastewater discharges from scattered houses on environmental conditions in small watercourses. Regional watercourse surveillance describes environmental conditions in biological terms, on the basis of the type and abundance of invertebrates. Monitoring is undertaken annually at some 880 stations spread over some 1 400 km of watercourse. Fish stocks are also measured at least once a year in the watercourses Stokkebækken, Stavis Å, and Vindinge Å.

Lakes

Environmental conditions are monitored in 34 large lakes in Fyn County. Two of these, Arreskov Sø and Søholm Sø, are also included in the NOVA 2003 surveillance programme and, therefore, are subject to extensive monitoring. This includes investigations of the input and loss of nutrients, physicochemical conditions in the water and sediment, phytoplankton and zooplankton, submerged plants, fish stocks, and, in Arreskov Sø only, the prevalence of hazardous substances and heavy metals. The regional monitoring programme includes an annual survey of one or two lakes to a similar extent as described for Arreskov Sø and Søholm Sø in the national programme. It also includes less-extensive investigations in 21 larger lakes that are part of the national surveillance programme connected to NOVA 2003. The lakes are investigated every three years (i.e. seven lakes each year). In addition, eight more lakes are examined on the same basis. Furthermore, the effects of various biological control measures, e.g. the removal of "undesirable" fish in an attempt to improve environmental conditions in selected lakes, are monitored.

Coastal waters

As part of the NOVA 2003 surveillance programme, Fyn County has identified a **"type area,"** Odense Fjord, as one out of six national "type areas". Additionally two **"representative areas,"** the South Fyn Archipelago and the cove Kertinge Nor, are identified. These three locations are the subject of an intensive programme to map all the important factors affecting environmental conditions in the areas. In the "type area" Odense Fjord the investigations also include analysis of hazardous substances, nutrient fluxes from the sediment, and modelling of water- and nutrient balances.

In open coastal waters, a station in the Little Belt has been selected for intensive monitoring as part of the NOVA 2003 monitoring programme. The surveillance is made in collaboration with Sønderjylland County Council. A station for intensive monitoring has also been selected in the Great Belt. In addition to meeting national requirements, the surveillance at both locations will meet the requirements of international conventions.

Regional surveillance in the Little Belt is a cooperation between the County Councils of Fyn, Vejle, and Sønderjylland, and includes investigations of chemical and biological parameters in the water column, benthic vegetation and animals, and the prevalence of hazardous substances in water and sediment. The regional programme also involves surveillance of a number of stations in open coastal waters that have been monitored since 1976. Mapping of oxygen depletion, and surveys of sediments and benthic vegetation and animals, are also made in those regions of Fyn's open coastal waters not included in the NOVA 2003 monitoring programme. Furthermore, annual surveys are also made at 4-5 of the 40 smaller fjords and coves/inlets around Fyn County.

Groundwater

Six groundwater monitoring areas (GRUMO areas), lying within the abstraction areas of six waterworks, have been identified in Fyn County. In the six GRUMO areas, 86 filters and 49 boreholes have been established. An analysis programme includes measurement of common constituents of groundwater, e.g. chloride, sulphate, nitrate, and 20 different inorganic trace elements (e.g. lead, cadmium, copper). The programme also includes analysis of 21 different types of synthetic organic contaminants (e.g. phenols, chlorophenols, detergents, MTBE), and a range of pesticides and their degradation products. In addition, analysis of freon in groundwater is also made.

In the land surveillance area in the catchment of the stream **Lillebækken**, shallow groundwater is monitored by collecting samples at 1, 3, and 5 m depth. Samples are collected on 1-6 occasions annually, and undergo the same analyses as samples from the GRUMO areas.

Seepage from contaminated grounds. Seepage of nutrients and/or hazardous substances from contaminated sites to groundwater and/or surface water is monitored by specific monitoring programmes that, in 1999, included 32 contaminated sites. The purpose of the surveillance is to follow developments in the composition and concentrations of the leached contaminants, with the aim of assessing if measures to protect groundwater and/or surface water should be implemented (see Chapter 9: Groundwater).

Atmospheric deposition

Denmark's counties are not required to monitor the deposition of contaminants present in the atmosphere. However, Fyn County Council has initiated a regional programme with four measuring stations (Årslev in central Fyn, Boelsmose in south-east Fyn, Birkholm in the South Fyn Archipelago, and at the Langø plantation on northern Fyn). Two samples (combining precipitation and dry deposition) are collected at each station every 14 days, giving roughly 200 samples for analysis of total nitrogen and phosphorus, inorganic nitrogen and phosphorus, sulphate, potassium, pH, and particulate matter. Samples from Birkholm are also analysed for chloride.

made, stations at which atmospheric deposition is monitored, and the groundwater and land catchment surveillance areas, termed GRUMO and LOOP, respectively. The enlarged map (insert) of the island of Ærø provides an example of the distribution of stations at which biological assessment of watercourse quality (saprobial stations) is made. In 1998, 883 saprobial stations were visited in Fyn County.

Photo: Bert Wiklund

4 Meteorology and Hydrology

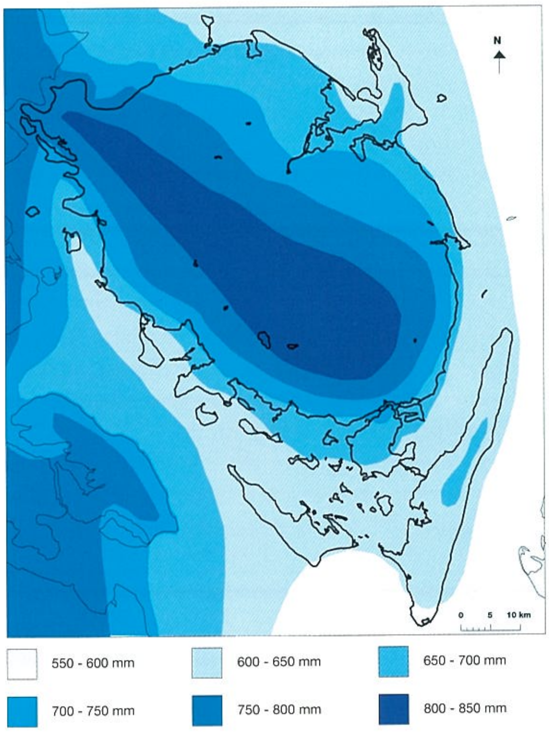


Figure 4.1
Annual rainfall distribution in Fyn County during the "norm" period 1961-1990. The distribution of rainfall on Fyn County follows topography (shown in Figure 1.1). Source: Danish Meteorological Institute.

Consideration of meteorological conditions is important when assessing data for the aquatic environment. It is often necessary to remove natural variations in measured parameters that result from changing meteorological conditions before the effects of human activities can be assessed reliably.

Precipitation during the winter half of the year (October - March) determines annual freshwater runoff, and thus also the proportion of excess nutrients leached from agricultural land. Precipitation during the summer half of the year (April - September) influences the growth and success of the year's crops, and so indirectly the proportion of excess nutrients remaining in agricultural land after crops have been harvested.

Air temperature and solar radiation influence warming of land and water masses and, therefore, also affect their biological and chemical processes. Examples include the growth of crops, the growth of algae in lakes and coastal waters, and the rate of decay of organic material in water bodies. The rate of degradation of pesticides and

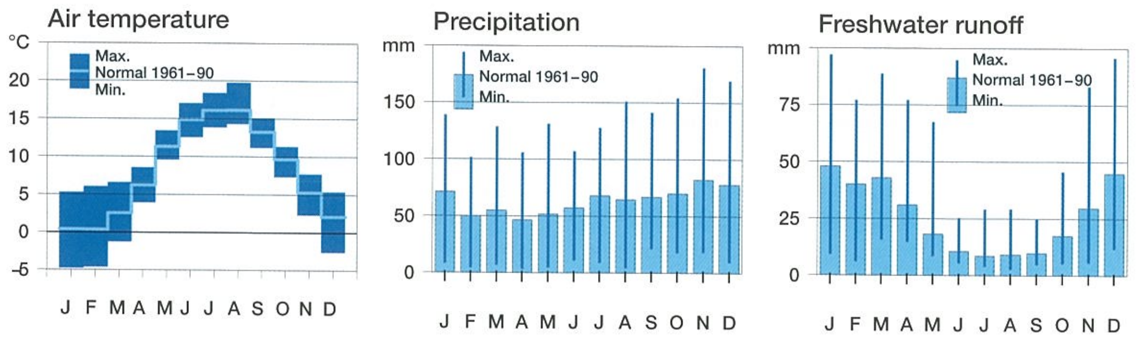


Figure 4.2
Monthly normal values, and maximum and minimum values for air temperature, precipitation, and freshwater runoff in Fyn County during the "norm" period 1961-1990. Sources: Danish Meteorological Institute and Fyn County Council.

other hazardous substances in the environment is also dependent on temperature. If it is cold, degradation is slow and there is a greater risk of the substance accumulating in the aquatic environment.

Wind affects the surface waters of lakes and shallow coastal areas. Strong winds can mix water masses, which may result in nutrient-rich bottom waters being brought to the surface. In addition, the general currents in Denmark's inner coastal waters are largely generated by wind action. Essentially, this is the result of westerly winds pressing the waters of the Skagerrak towards the Baltic Sea, and easterly winds pressing the waters of the Baltic Sea towards the Skagerrak.

The climate of Fyn

Climate is here taken to mean the average, or typical, weather during a period of 30 years. Currently, norms for the period 1961-1990 are used.

In general, the climate of Fyn County, like that of the rest of Denmark, is influenced by the fact that Denmark is located on the western side of a continent at a latitude of roughly 55°N. Westerly winds predominate, and the climate and temperature are essentially maritime, reflected in relatively cool summers and mild winters. Denmark also receives a relatively large amount of precipitation, particularly in the summer and autumn, when absolute humidity is highest. However, a significant amount of precipitation falls throughout the year. Fyn is the warmest part of Denmark, the mean annual temperature in the centre of Fyn being roughly a degree higher than that of northern Jylland (Figure 4.3). The largest amount of precipitation falls on central Jylland, decreasing over Fyn and further east towards Sjælland. In general, less precipitation falls along easterly coastlines and over the water.

The climate of Fyn is relatively constant in meteorological terms. The variation that is present is primarily the result of the distribution of water and land, and the topography of Fyn (see Figures 4.1 and 4.3).

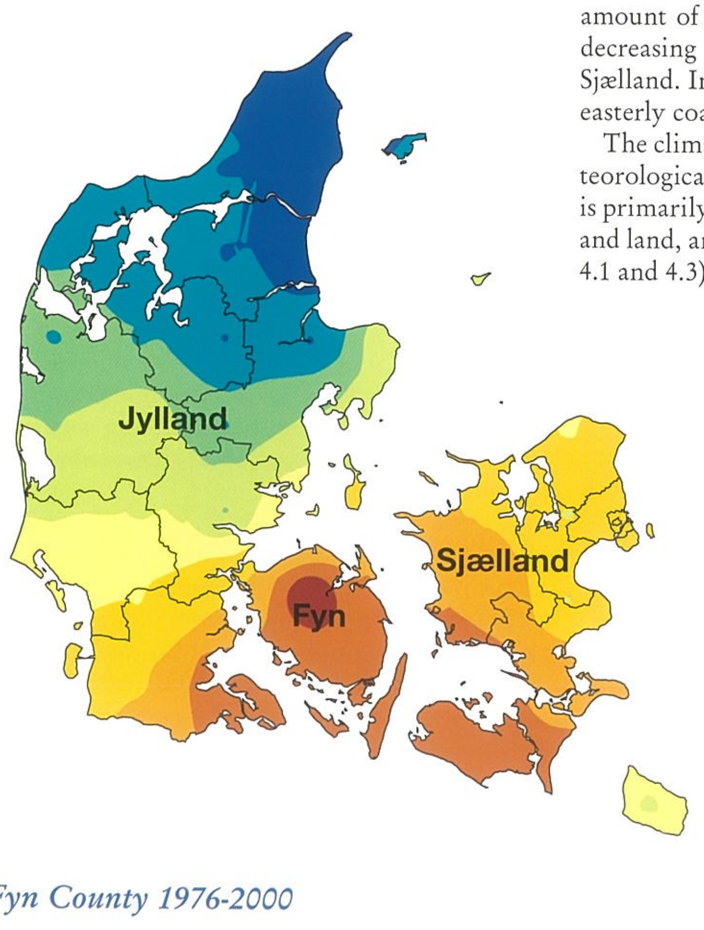


Figure 4.3
Mean annual temperatures in Denmark during the period 1989-1996. Source: Windolf et al. (1997).

Precipitation

The greatest amount of precipitation falls on inland Fyn and the least at the coast (Figure 4.1). The annual variation in precipitation on Fyn is roughly 600 to 800 mm. The annual precipitation for the whole of Fyn County is on average 740 mm (1961-90). The distribution of precipitation follows topography, with the greatest amount falling on the highest parts of Fyn (see Figures 4.1 and 1.1). Precipitation is normally higher in the second half of the year (Figure 4.2).

Air temperature

The annual mean air temperature on Fyn is 8.2°C (1961-90), which is 0.5°C above the national average. During the period 1988-1994, with the exceptions of 1993 and 1996, the annual temperature has been markedly over the annual mean temperature. 1989, 1990, 1992, and 1994 were among the warmest years of the last century. The winters, but also a number of summers, have been warmer than normal. The summer of 1997 was exceptionally warm (Figure 4.5 and 4.6).

Wind

Wind is generally strongest over water. The winter is normally the most windy. In relation to the aquatic environment, wind conditions during the summer half of the year are of particular interest, as strong winds can mix surface and bottom waters, allowing oxygen to reach the bottoms waters and reduce or prevent oxygen depletion.

The last 10-15 years have been relatively windy, providing a large amount of wind energy to mix and oxygenate water masses during the summer months, though the summer months of 1995 and 1997 were relatively calm (Figure 4.4)

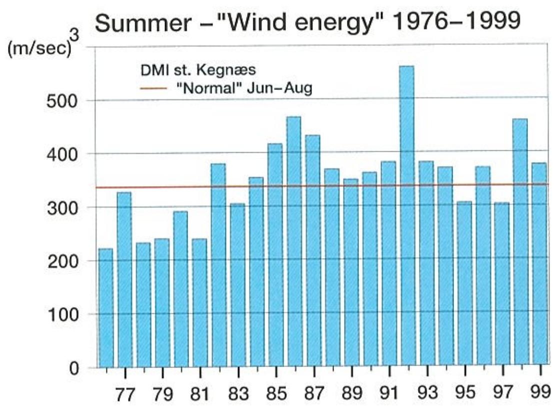


Figure 4.4
Wind speed (m/s)^3 is proportional to the amount of energy that wind delivers to open water surfaces, energy that can be used to mix water masses. As a measure of the wind energy delivered to the coastal waters around Fyn during the summer months, this figure shows cubed wind speed (mean of individual measurements taken every three hours) during June to August for the period 1976-1998.

Five years with marked variation in precipitation and freshwater runoff: 1994-1998

The five years between 1994-1998 include some of the most extreme variations in precipitation registered over the last 100 years. This is reflected in measurements from Danish Meteorological Institute's monitoring station in the rural town of Håstrup, on southern Fyn, where precipitation has been registered daily since 1897 (see photograph).

Photo: Loaned by Knud Vølund, Haastrup

Two successive years, the hydrological years 1994/95 and 1995/96, were the wettest and driest years, respectively, during the last 100 years. In 1994/95 (the wettest) 1012 mm of precipitation fell, which is 37% more than the norm for 1961-1990. In 1995/96 (the driest) only 410 mm of precipitation fell, which is 43% below the norm for 1961-1990, and the lowest recorded annual precipitation.

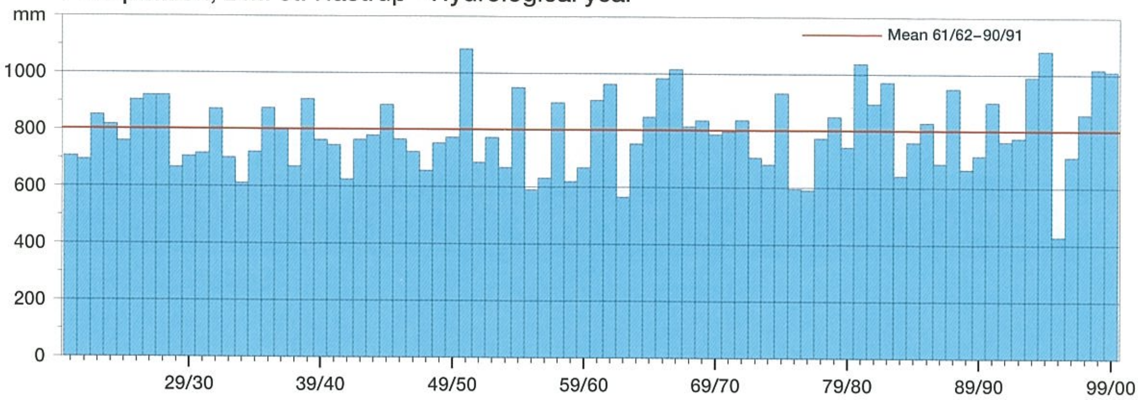
A period of low precipitation began in the summer of 1995 and continued for two-and-a-half years until January 1998. As a result, freshwater flow in watercourses in the County was below average for every month during this period (Figure 4.6).

The low precipitation also meant that groundwater formation and leaching of nutrients from fields were both considerably lower than normal. In 1995/96 there was essentially no accumulation of groundwater or leaching of nutrients.

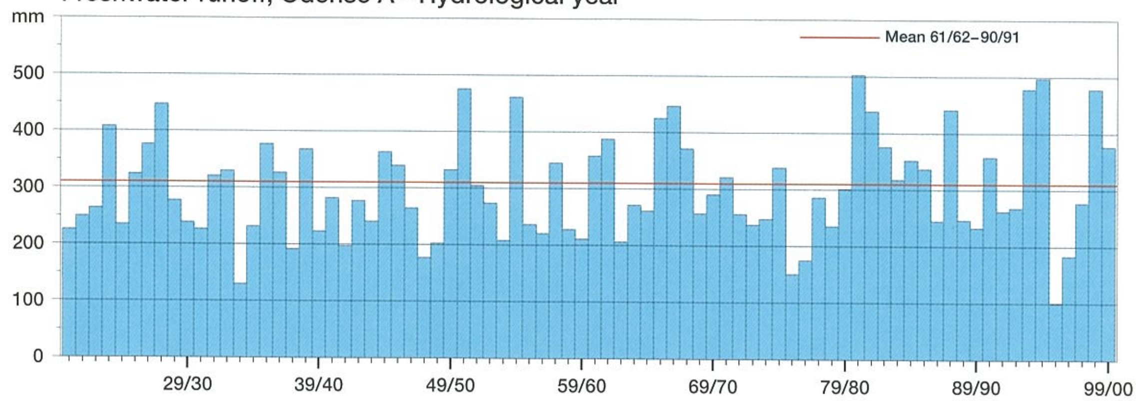
Significant variations in monthly precipitation also occurred during the period 1994-1998. For example, precipitation in October 1998 was the highest on record, and resulted in greatly increased flow in the County's watercourses. As a consequence, flooding occurred at many locations, particularly low-lying areas adjacent to watercourses.

Weather and freshwater runoff 1920–1999/2000

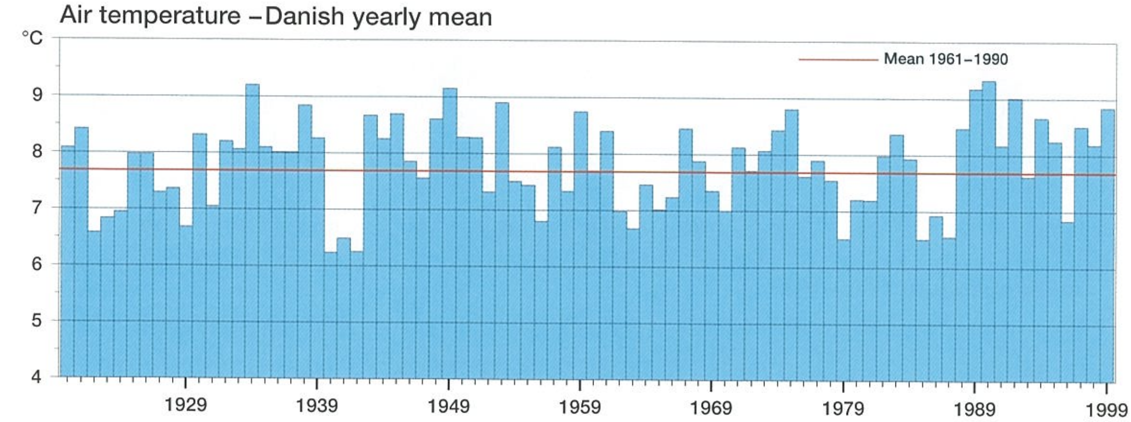
Precipitation, DMI st. Håstrup – Hydrological year



Freshwater runoff, Odense Å – Hydrological year



Air temperature – Danish yearly mean



Air temperature – Danish summer mean (June–August)

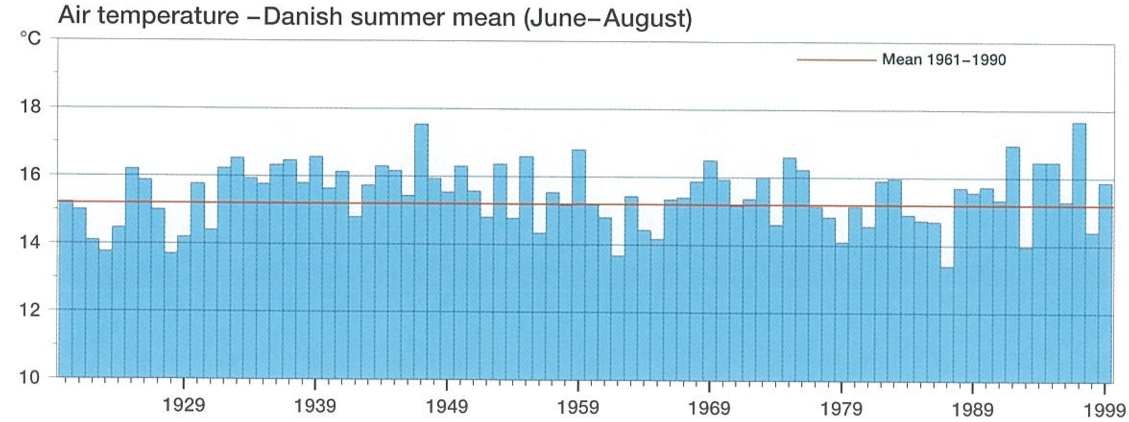


Figure 4.5 Precipitation, freshwater runoff, and air temperature in Fyn County between 1920 and 1998/99. The data were collected at weather stations in the County and national weather stations (air temperature).

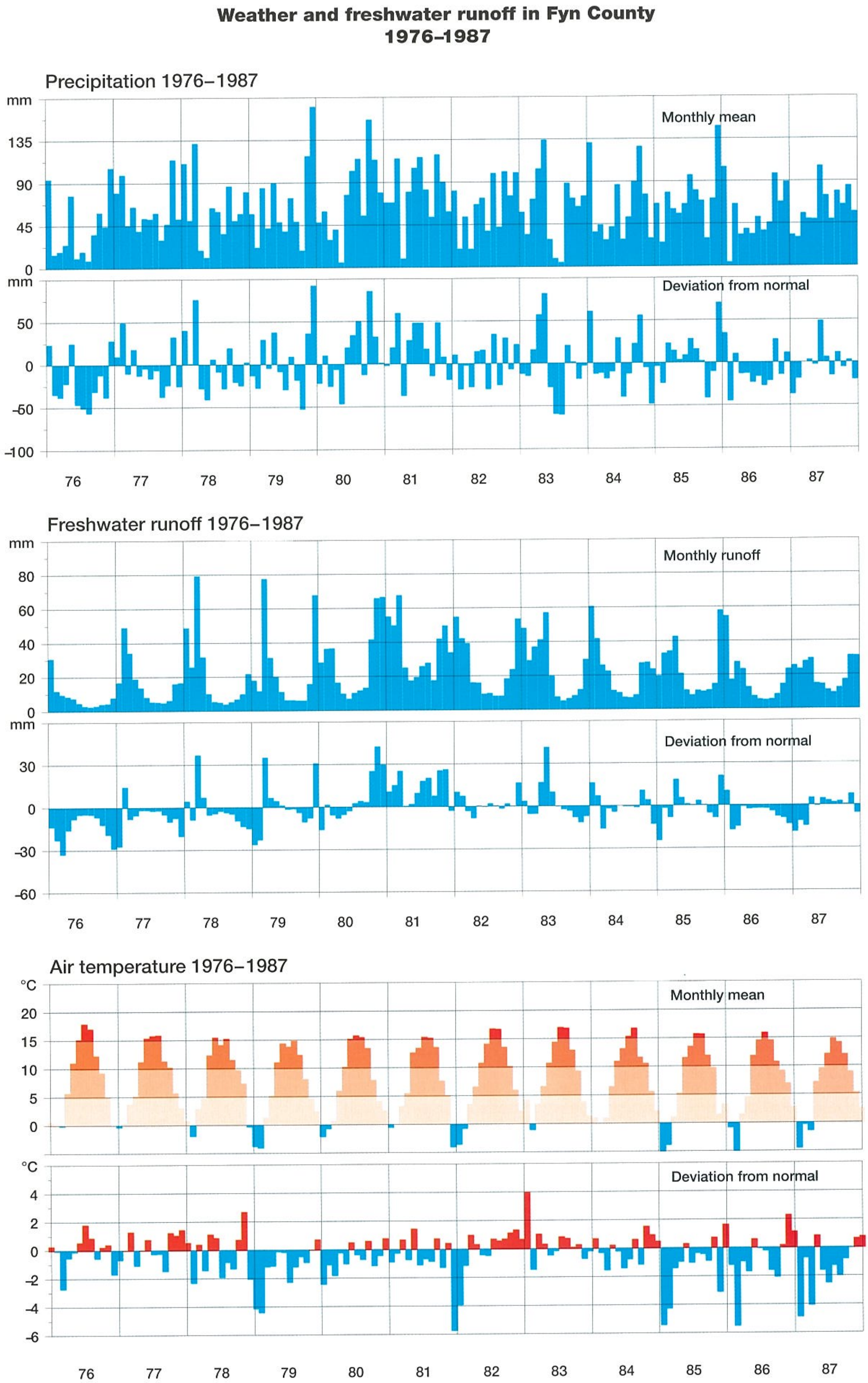
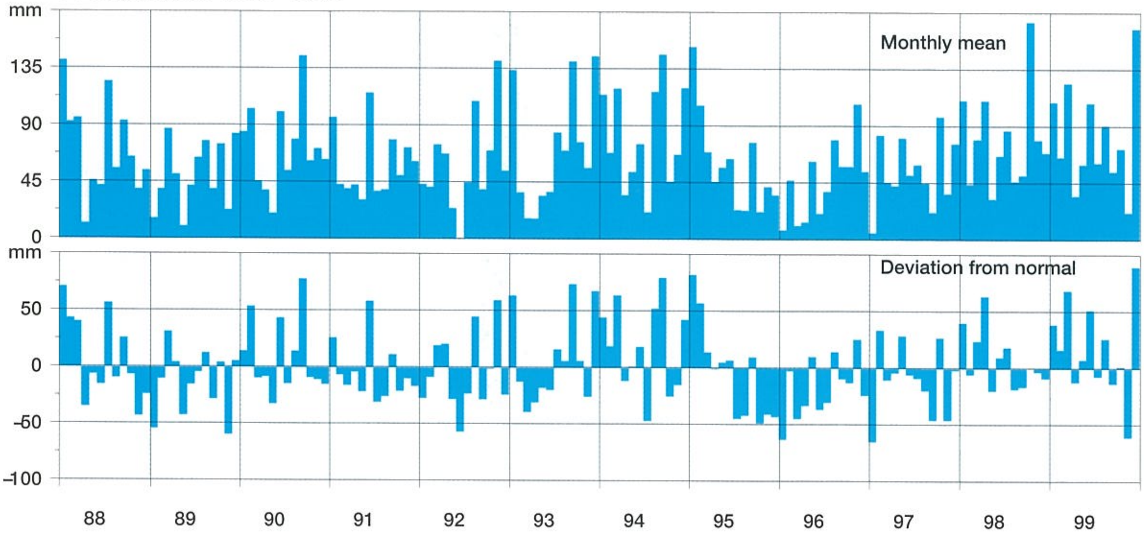


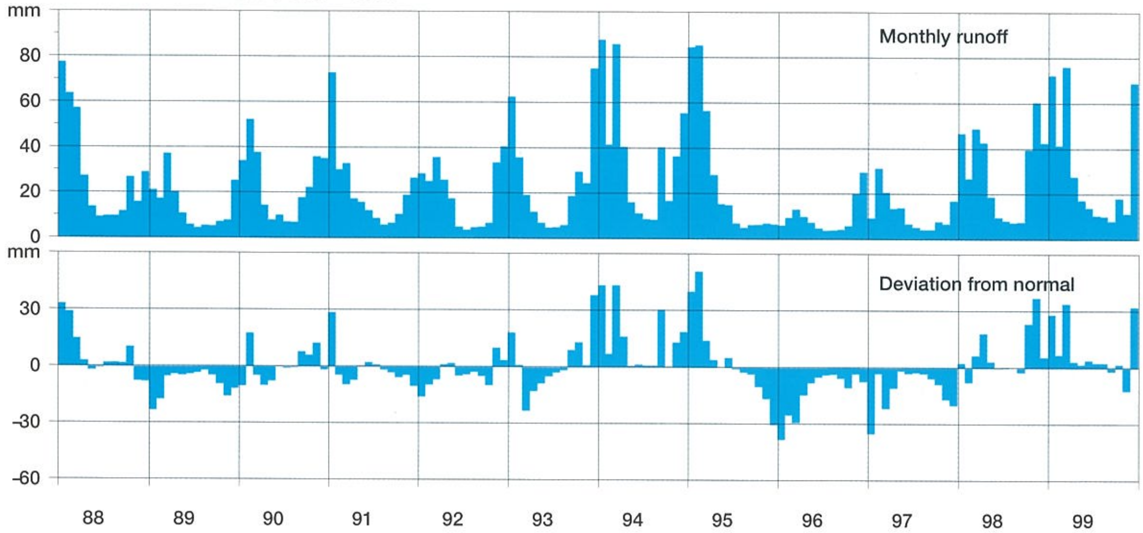
Figure 4.6
Monthly data for precipitation, freshwater runoff, and air temperature for Fyn County during the period 1976-1998. The variation between these values and the monthly normal values for the period 1961-1990 is also shown. Sources: Danish Meteorological Institute and Fyn County Council.

Weather and freshwater runoff in Fyn County 1988–1999

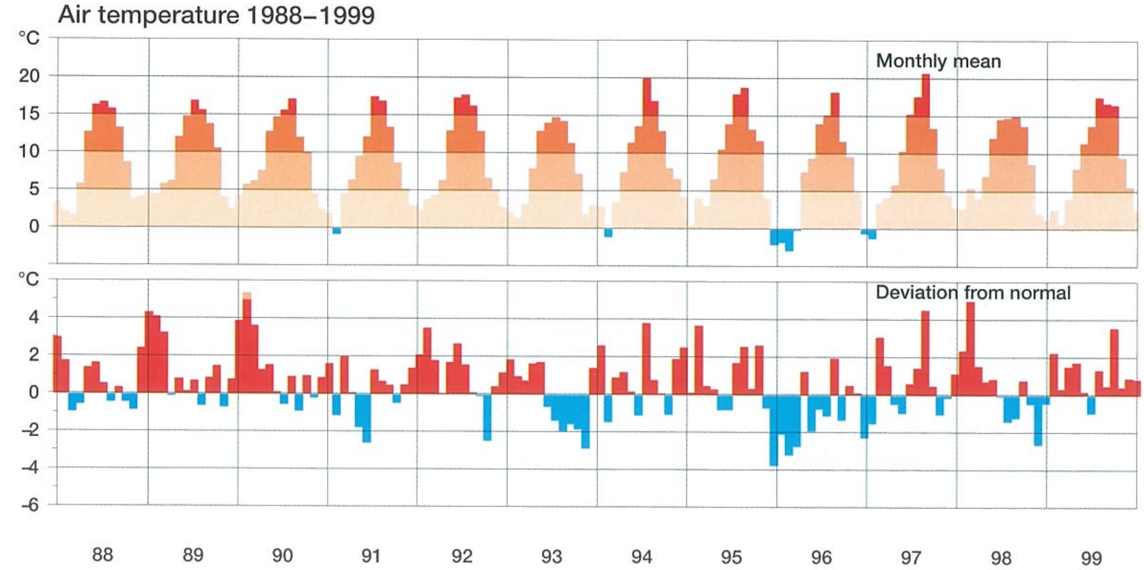
Precipitation 1988–1999



Freshwater runoff 1988–1999



Air temperature 1988–1999



Freshwater runoff

The annual mean freshwater runoff from watercourses in Fyn County (1961-1990) is 255 mm/yr, equivalent to 8.1 l/s/km^2. Freshwater runoff varies both on a nationwide basis and locally in a region such as Fyn, due to differences in soil characteristics and amounts of precipitation.

Freshwater output from watercourses accounts for roughly 35% of the annual precipitation falling on Fyn. Freshwater output follows periods of precipitation in the winter half of the year (October - March). Roughly half the annual freshwater output from the County's watercourses occurs during the months of January, February, and March.

Water balance in Fyn County

Water in the environment is in constant motion: in the atmosphere, in the sea, and on land. Water is exchanged between the different physical compartments of the environment in a closed cycle, and watercourses have a central role in this cycle. The Geological Survey of Denmark and Greenland (GEUS) has produced a model to describe the water cycle on Fyn. The model is based on average values for, among other factors, precipitation, freshwater runoff, and groundwater levels. A schematic diagram of the model is shown in Figure 4.7. It includes the mean size of the various compartments and flows in the water cycle based on data for 1989-1996.

Water evaporating from the sea is blown over the land where it falls as precipitation. An average of 740 mm of precipitation fell annually on Fyn County during the period 1989-1996. A considerable proportion of precipitation evaporates, either directly from the soil surface, or via the transpiration of plants that have taken up water in the root zone. The remaining precipitation (net precipitation) runs directly to watercourses or the sea, or enters them via drains or ditches, or enters the groundwater. Surface water and shallow groundwater emissions include not only rain water that runs off the ground surface into watercourses, but also rainwater collected by drainage and sewerage systems in urban areas and discharged into watercourses.

The geology of the majority of Fyn County is characterised by an impermeable layer of clay. This means that only a small portion of the net precipitation actually percolates to groundwater. In addition, more than 50% of the agricultural land in Fyn County is drained. Thus, the majority of the net precipitation quickly runs to watercourses.

In summer, the flow of water in the County's watercourses is largely determined by the entry of water from deep aquifers. As a result, watercourse flow is low during the summer. During the period 1989-1996, the flow of freshwater from deep aquifers to watercourses constituted only 38 mm out of the total of 233 mm annually discharged by watercourses in Fyn County (Figure 4.7).

At the same time, a significant amount of water is abstracted from deeper aquifers to supply drinking water. This can create local environmental problems in watercourses if the requirement to supply drinking water is not balanced by the need to ensure that the flow of groundwater to watercourses is sufficient to maintain their communities of plants and animals.

Factors controlling freshwater runoff

Several factors influence the flow of fresh water in watercourses. The most important are meteorological and geological conditions, though human activities can also play a role.

During the summer (April - September) only a small proportion of precipitation enters watercourses, the majority either evaporates or is taken up by plants.

Soil characteristics greatly influence how much precipitation percolates to groundwater and how much quickly runs to watercourses via drains, shallow groundwater, and surface runoff.

In the more clayey catchments of eastern Denmark (i.e. eastern Jylland, Fyn, and Sjælland) aquifers are often capped by an impermeable layer of clay. In addition, the agricultural land in these areas is usually drained, allowing excess precipitation to quickly run from fields to watercourses.

Watercourses in eastern Denmark are thus primarily fed by shallow groundwater and surface runoff. This is reflected in large variations in freshwater flow over the year, with highest runoff during the winter months and occasional drying up of the upper reaches of watercourses during the summer.

In addition, these watercourses 'react' quickly to large, sudden precipitation events, in that flow in the watercourses increases rapidly, particularly in the winter months when evaporation is low.

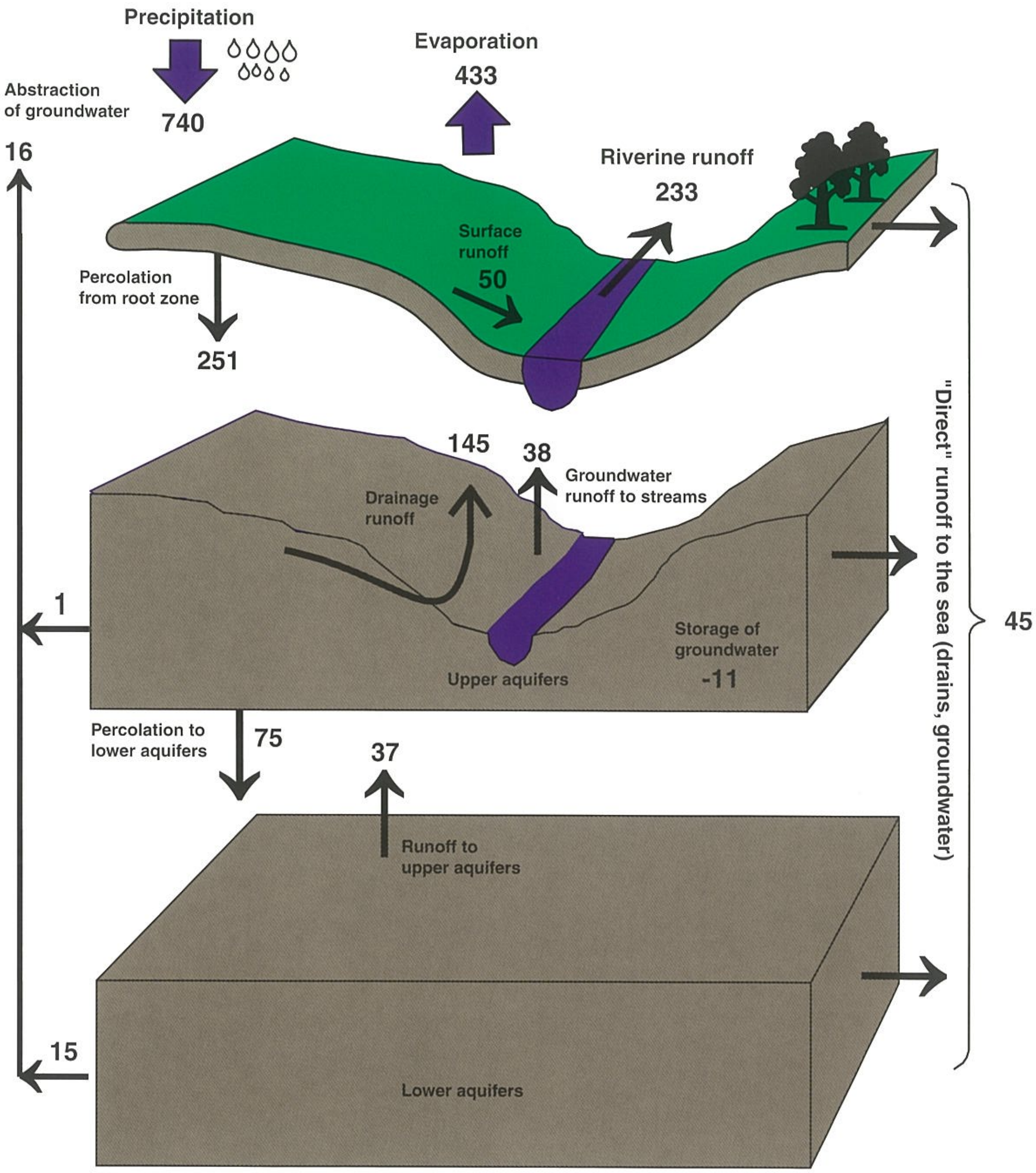


Figure 4.7
The water cycle in Fyn County during the period 1989-1996, calculated using a model produced by the Geological Survey of Denmark and Greenland. The values for the compartments and flows are means (mm/year) based on data for 1989-1996. The diagram is divided into the various "calculation layers" of the model for which calculations are made.

'Fynsværket' power plant, Odense. *Photo: Courtesy of 'Fynsværket'*

Slurry spreading. *Photo: Fyn County Council*

Ejby Mølle wastewater treatment plant. *Photo: Fyn County Council*

Dry cleaners. *Photo: Fyn County Council*

5 Sources of Pollution

The aquatic environment of Fyn County is affected by pollution from a range of sources. Pollution enters aquatic habitats via watercourses, from direct wastewater discharges, and via atmospheric deposition. The coastal waters of Fyn also receive pollutants from adjacent water masses.

Groundwater pollution is primarily the result of percolation of nitrogen (nitrate) and toxic chemicals. In lakes, fjords, and coastal waters, the input of nutrients and hazardous substances creates environmental problems. In watercourses, the entry of oxygen-consuming substances and hazardous substances, in particular, causes problems.

This chapter examines the contributions of the individual sources of pollution, annual variations in pollution loads, and developments in the extent of pollution. The effectiveness of various measures implemented to limit pollution of the aquatic environment will also be examined. Attention will be focussed on nutrient pollution, as current knowledge of the effects of toxic chemicals on the aquatic environment is quite limited.

Primary sources of pollution entering Fyn's aquatic environment

- **Discharges of wastewater from households and industry**
- **Loss of nutrients from agriculture to the air and water**
- **Loss of pesticides etc. used in agriculture, by municipal authorities, and private use of pesticides and other hazardous substances**
- **Emissions from industry and motor traffic to the atmosphere**
- **Leaching from old waste disposal sites and grounds contaminated by chemicals**

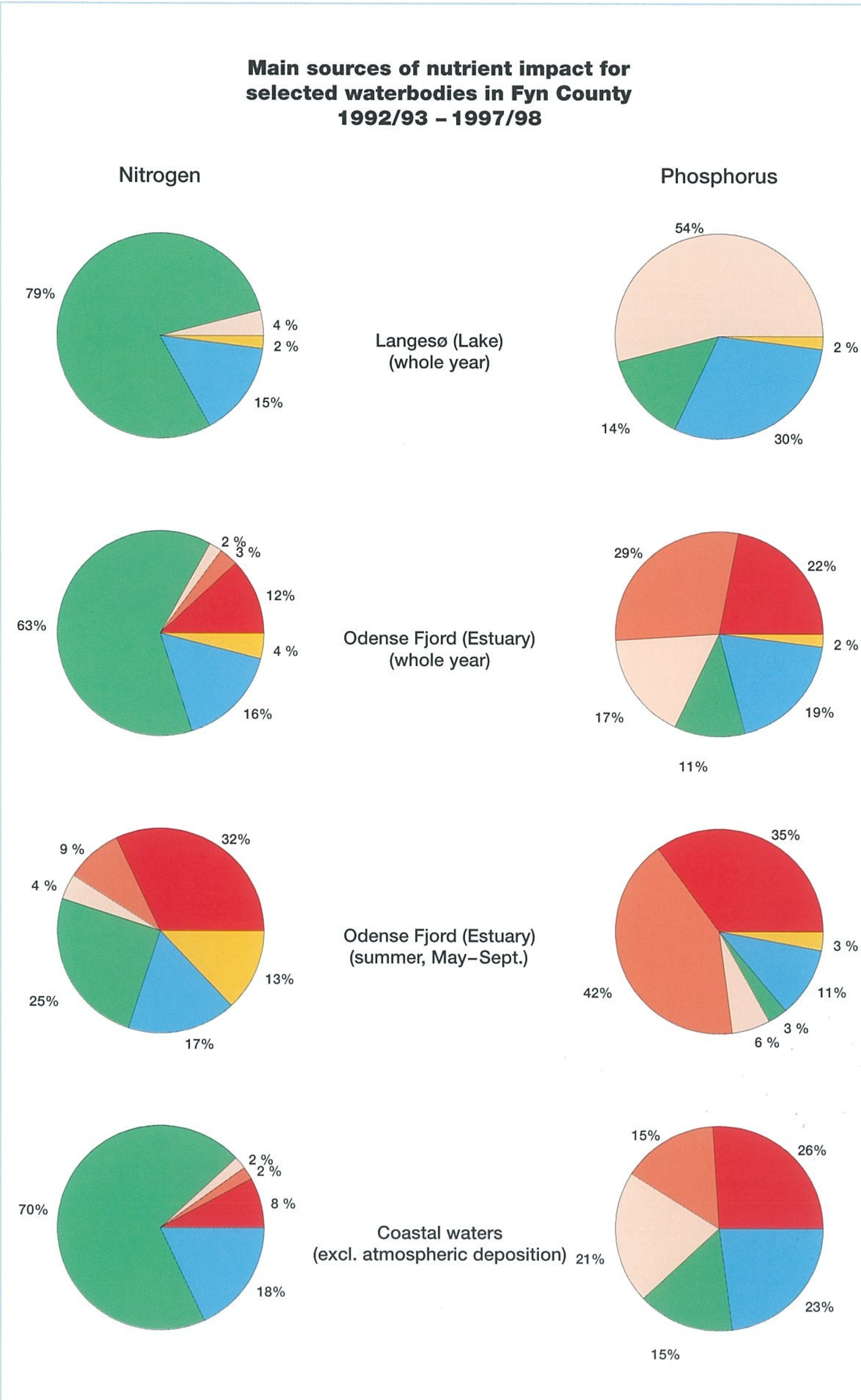


Figure 5.1
Primary sources of nutrient impact for selected waterbodies in and around Fyn County. The values are annual means for the period 1992/93 to 1997/98. Average summer values are also shown for Odense Fjord. With respect to phosphorus, it is difficult to separate the contribution of wastewater from scattered homes in rural areas and the contribution from agriculture. There is, however, more certainty in the combined value for the two sources.

Atmospheric deposition:

Atmospheric deposition to waterbodies of nutrient originating from agriculture, motor traffic, industry, power stations etc.

Wastewater discharges:

Discharges of wastewater from municipal wastewater treatment plants, individual industries, and waste disposal sites

Discharges of rainwater from sewers and surfaced areas.

Wastewater from scattered homes in rural areas

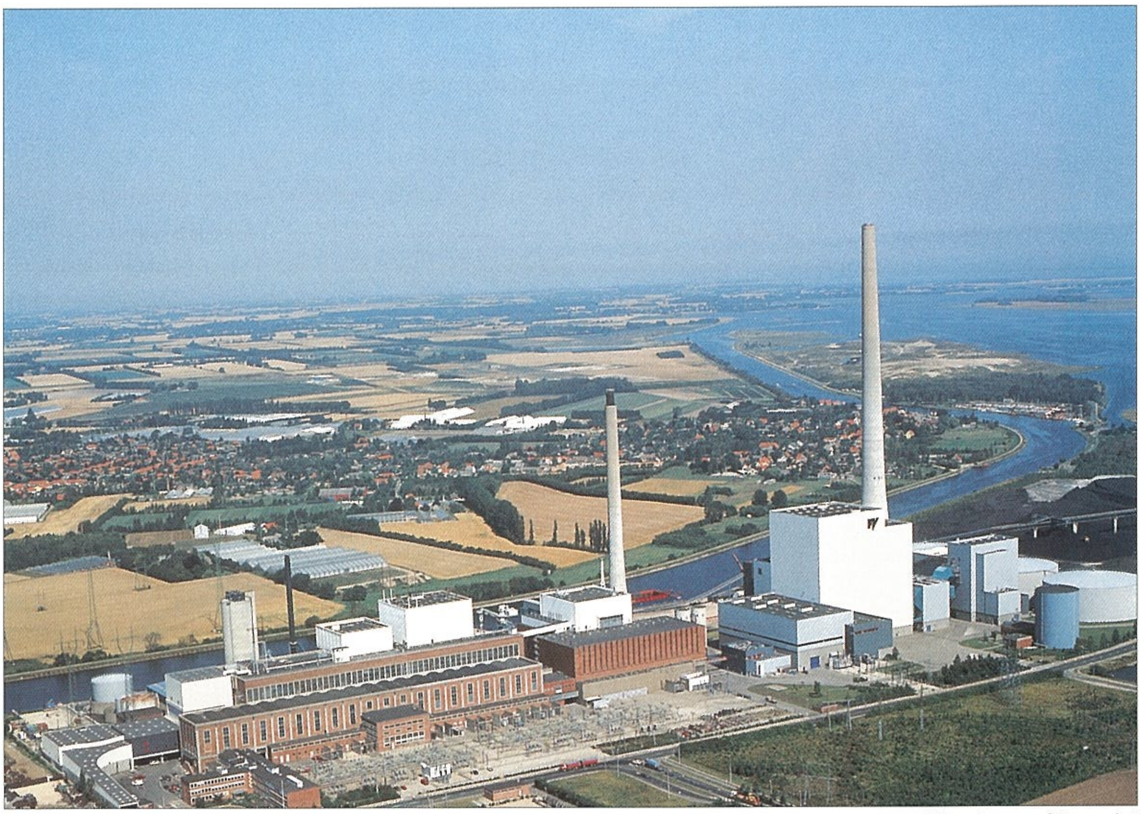
Background output:

Natural (background) loads entering lakes and coastal waters via watercourses

Runoff from agriculture:

Agricultural practices

Power plants can be an important source of nitrogen oxide (NO_x) pollution of the atmosphere. Nitrogen oxides can be transported over large distances before being deposited, partly via precipitation, on land and waterbodies. See section 5.1.



'Fynsværket' power plant. Photo: Courtesy of 'Fynsværket'

Ammonia that evaporates from slurry (liquid animal manure) returns to the land and waterbodies by several routes, including via precipitation. It has been calculated that roughly one-quarter of the ammonia that evaporates from animal manure originates from slurry tanks and manure heaps (Andersen et al., 1999). See section 5.1 on nutrient deposition on the land and waterbodies, and section 5.3 on evaporation of ammonia from agricultural activities.

Slurry tank. Photo: Bjarne Andresen, Fyn County Council

Nitrogen losses from Fyn County in the mid 1990s

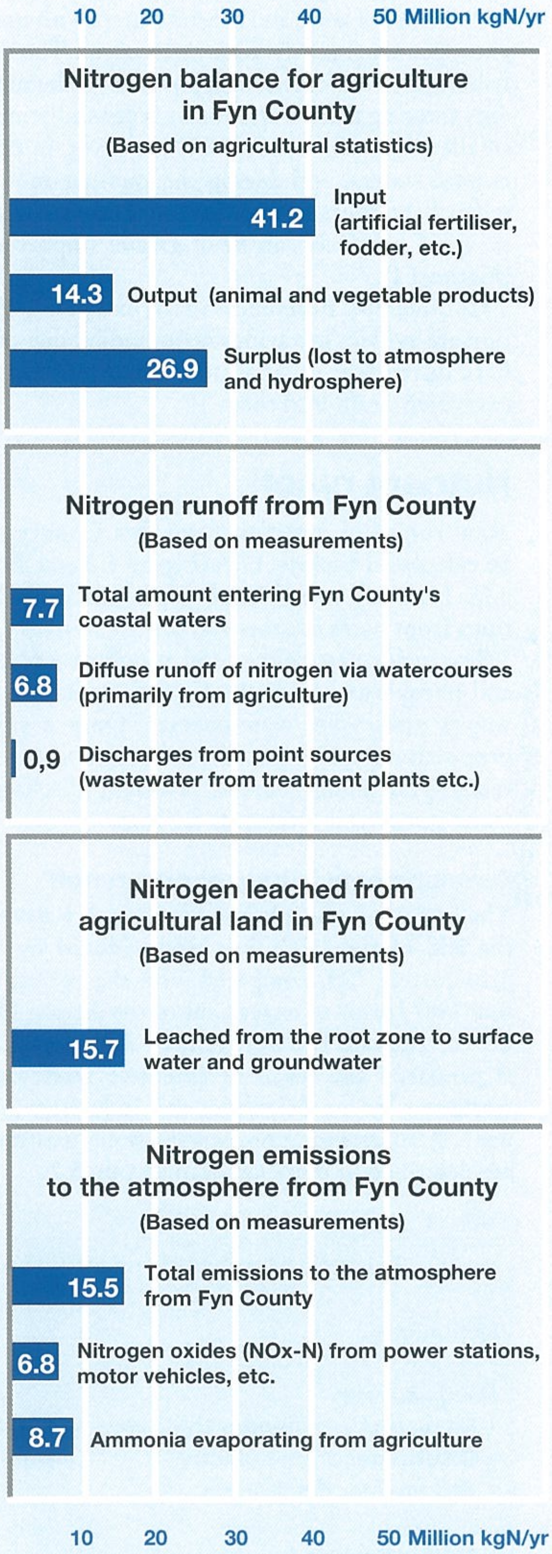
Nitrogen is an essential nutrient for life. However, nitrogen is often also a major pollutant of the aquatic environment, due to large losses of nitrogen arising from human use of nitrogen-containing products and materials. Large losses of nitrogen to the environment are especially associated with agriculture and the burning of fossil fuels. Nitrogen lost to the environment is distributed by wind- and water currents.

The diagram (right) presents some of the major nitrogen sources and routes by which nitrogen is lost from Fyn County. Each is examined in more detail in sections 5.1, 5.2, and 5.3.

Artificial fertilisers and fodder consumed by agriculture are the dominant sources of nitrogen entering the environment. Only about one-third of the nitrogen consumed by agriculture is incorporated into agricultural produce; the remainder is lost to the atmosphere and hydrosphere.

The calculated nitrogen surplus for agriculture in Fyn County is essentially equivalent to the amount of nitrogen leached from agricultural land plus the amount of nitrogen in ammonia evaporating to the atmosphere. These two values are determined independently.

Diffuse runoff of nitrogen to watercourses accounts for less than half of the nitrogen leached from fields. This is explained by the process of nitrate reduction/denitrification, via which nitrate in water leaching from fields toward groundwater and surface water is converted to nitrogen gas which is released to the atmosphere. At the present, the amount of nitrogen that is denitrified is slightly greater than the amount that enters watercourses via diffuse runoff. Measures in the Action Plan for the Aquatic Environment II are expected to increase denitrification via the creation of wetlands. It is expected that some 1 600 ha of wetlands will be established in Fyn County, and with a mean denitrification capacity of 350 kg N/ha/yr, denitrification would be increased by 0.56 million kg N/yr. This represents roughly an 8% reduction in diffuse runoff of nitrogen to watercourses. See section 5.3 on loss of nitrogen from agriculture.



5.1 Nitrogen and phosphorus pollution of the aquatic environment

Nutrients enter aquifers almost exclusively as a result of leaching from fields.

Pollution of lakes and coastal waters with nutrients occurs primarily via watercourses. The contribution of atmospheric deposition to the nutrients entering these waterbodies is generally much smaller than of watercourses. However, in open coastal waters, and during the summer months when watercourse flow is low, atmospheric deposition of nutrients can be of greater importance (Figure 5.1).

Considerable differences in the extent of pollution are evident in various waterbodies, due partly to differences in land use in the catchment areas which drain into them.

Nutrient runoff

Total runoff of nutrients from Fyn County can be calculated back to 1976 (Figure 5.2 and Table 5.1). Nutrient runoff is divided into contributions from point sources and diffuse sources.

The major part of the total runoff of nitrogen and phosphorus from the County to its coastal waters occurs via watercourses. Only a small proportion (< 6%) of the total input occurs directly from point sources, primarily discharges from wastewater treatment facilities.

Developments in phosphorus runoff

The input of phosphorus to coastal waters at the end of the 1990s has been reduced by approximately 70% compared with the period before 1987 (prior to enactment of the Action Plan for the Aquatic Environment I - APAE I). This is primarily the result of extensive wastewater treatment by municipalities and industries (Figure 5.2). Efforts to improve wastewater treatment are described in more detail in section 5.2.

Sources of nutrient runoff

Definitions

Point sources:
- **Municipal wastewater treatment facilities**
- **Discharges from industry**
- **Stormwater discharges**

Diffuse sources:
- **Natural (background) contribution**
- **Wastewater from scattered homes**
- **Runoff from agricultural land**

In the 1970s and 1980s, point sources were the primary source of phosphorus runoff from the County to its coastal waters. The reduction in discharges from point sources means that such sources now constitute only about 33% of total phosphorus runoff from Fyn.

Currently (late 1990s), approximately 67% of phosphorus runoff from Fyn originates from so-called diffuse sources. Some two-thirds of this diffuse emission is related to human activities, including discharges of wastewater from scattered homes in rural areas and loss of phosphorus from agricultural land. The remaining one-third of diffuse runoff of phosphorus is of natural origin.

The amount of phosphorus discharged by scattered homes in rural areas is now comparable to that discharged from municipal wastewater facilities into watercourses. In many cases, wastewater discharges from scattered homes and loss of phosphorus from arable land together constitute half or more of total phosphorus runoff to aquatic habitats (Figure 5.1).

Developments in nitrogen runoff

Nitrogen runoff to coastal waters at the end of the 1990s has been reduced by 20-25% compared with the period before 1987. Thus, there is still a long way to the objective of a 50% reduction in nitrogen runoff to the marine environment. Failure to meet the objective is primarily attributed to agriculture still being far from achieving a 50% reduction in nitrogen runoff. The objectives, set out in the APAE I, for reductions in emissions from wastewater treatment facilities were met already in 1992. The effects of initiatives to improve wastewater treatment are described in section 5.2 and the effects of initiatives to reduce agricultural emissions in section 5.3.

Nitrogen leached from agricultural land is the dominant source of nitrogen loading of aquatic habitats. At the end of the 1990s, agriculture accounted for roughly 70-75% of total runoff of nitrogen from the County to its coastal waters. Wastewater discharged from municipal wastewater facilities, industry, and scattered homes, and stormwater discharges of wastewater together constitute only some 5-10% of the total runoff of nitrogen from Fyn County. The remaining proportion (approximately 20%) is accounted for by background (natural) runoff.

Input of freshwater and nutrients to coastal waters

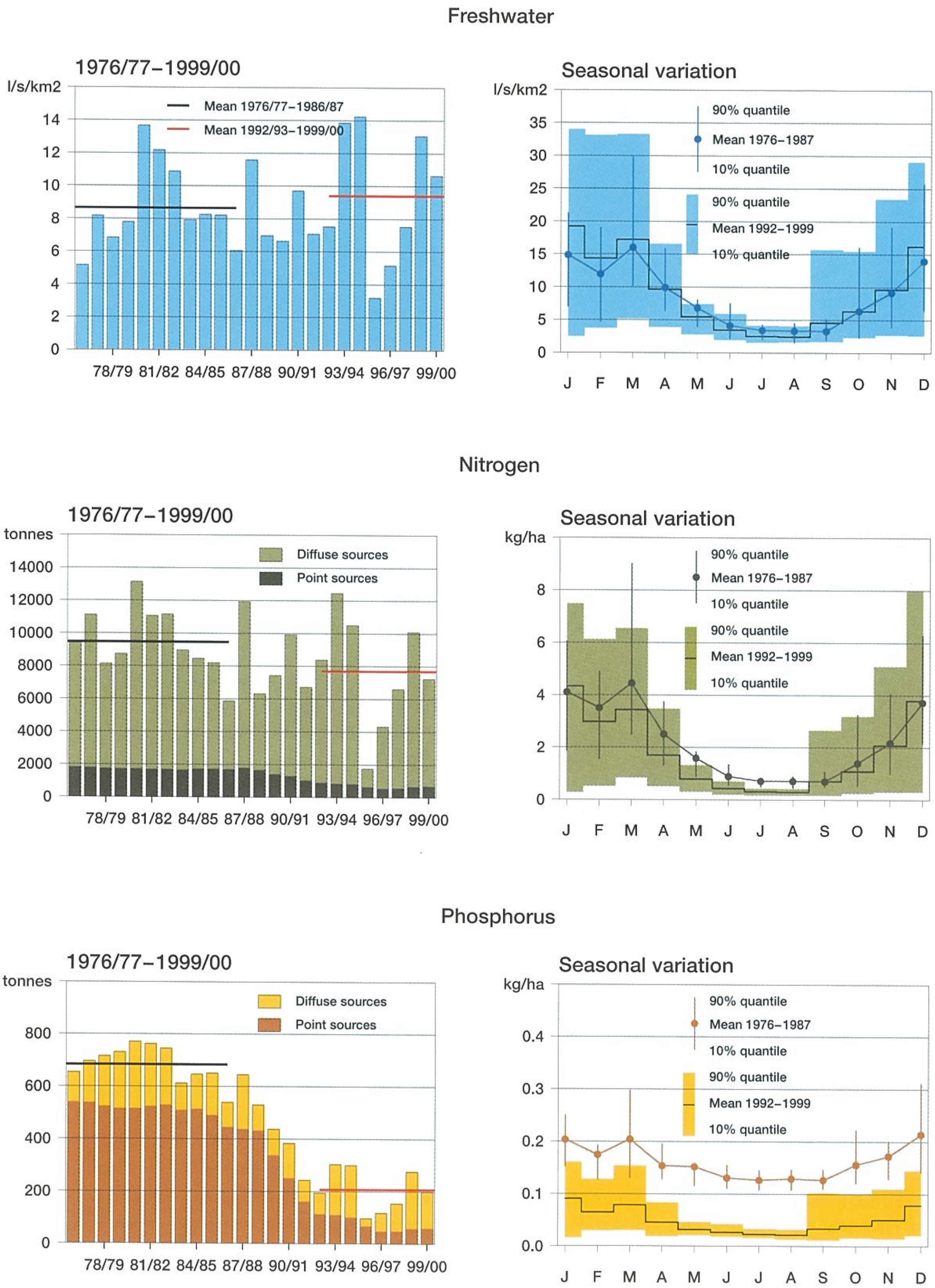


Figure 5.2

Left column:
Total runoff of freshwater, nitrogen, and phosphorus from Fyn County to its coastal waters during the period 1976/77 to 1999/00. Runoff is presented for the hydrological year (1 June to 31 May). Nutrient runoff is divided into the contributions from point sources (primarily discharges from wastewater facilities) and discharges from so-called diffuse sources (primarily nutrients leached from agricultural land). See also Figure 5.1.

Right column:
Monthly variation in runoff of freshwater, nitrogen, and phosphorus. The period 1976-1987 - prior to enactment of the Action Plan for the Aquatic Environment I - is compared with the period 1992-1999 after modernisation of wastewater treatment plants in Fyn County. The nutrient loads are based on measurements in 19 watercourses, discharges from municipal wastewater facilities and industry, and storm water discharges. Monthly runoff data for the period 1976-1999 are provided in Appendix 1.

Nutrient runoff from Fyn County 1976-1999											
Year	Freshwater runoff	Nitrogen runoff					Phosphorus runoff				
	l/sec/km²	Point tons/yr	Diffuse tons/yr	Total tons/yr	Total kg/ha	Diffuse kg/ha	Point tons/yr	Diffuse tons/yr	Total tons/yr	Total kg/ha	Diffuse kg/ha
1990	9.0	1447	8471	9917	28	24	292	126	418	1.20	0.36
1991	8.3	1098	6706	7803	22	19	193	107	299	0.86	0.31
1992	7.4	963	7167	8130	23	21	118	84	202	0.58	0.24
1993	9.5	831	8986	9816	28	26	107	128	235	0.67	0.37
1994	14.3	900	10487	11387	33	30	117	192	310	0.89	0.55
1995	10.3	716	6557	7273	21	19	78	133	212	0.61	0.38
1996	3.8	571	2404	2975	9	7	52	48	100	0.29	0.14
1997	4.5	531	2652	3183	9	8	42	56	98	0.28	0.16
1998	11.4	682	9533	10215	29	27	57	184	241	0.69	0.53
1999	12.0	697	7669	8366	24	22	61	185	246	0.71	0.53
1976-1987:											
Mean	8.4	1746	7489	9234	26	21	510	164	674	1.93	0.47
Maximum	13.7	1831	10414	12101	35	30	549	275	788	2.26	0.79
Minimum	3.1	1647	2584	4413	13	7	412	38	544	1.56	0.11
1989-1999:											
Mean	8.7	895	6769	7664	22	19	135	120	255	0.73	0.34
Maximum	14.3	1447	10487	11387	33	30	372	192	446	1.28	0.55
Minimum	3.8	531	2404	2975	9	7	42	48	98	0.28	0.14

Table 5.1
Total runoff of freshwater, nitrogen, and phosphorus from Fyn County to its coastal waters, divided into point sources and diffuse sources, during the period 1976-1999. The appendix includes data dating back to 1976 (Appendix 3).

Hydrological year definition:

1 June to 31 May

Nutrient runoff is 3-7 times greater in wet years than in dry years

There is considerable year-to-year variation in the runoff of nutrients. This is primarily due to annual variation in precipitation which contributes to variation in freshwater flow and leaching of nutrients from the soil (Figure 5.2).

Annual variation in nutrient runoff, due to variation in the amount of precipitation, may be greater than the target reductions for nutrient runoff set in the Action Plan for the Aquatic Environment.

In the wet hydrological year 1993/94 nitrogen runoff to coastal waters was an average of 33.4 kg nitrogen per hectare for the total land area of Fyn. In comparison, nitrogen runoff in the dry year 1995/96 was only 5 kg N/ha. Thus nitrogen runoff is some 6-7 times greater in wet years than in dry years. Similarly, phosphorus runoff was 0.8 kg phosphorus per hectare in 1993/94 compared with 0.3 kg P/ha in 1995/96.

In the dry hydrological years 1995/96 and 1996/97 nitrogen runoff from Fyn County was 81% and 54%, respectively, lower than the average in the period prior to the introduction of the APAE I. Such emissions are considerably lower than the Plan's general objective of a 50% reduction in nitrogen runoff. However, when emissions in these years are adjusted to account for the low water flow, there is no basis for stating that the Plan's objectives for reduced nitrogen runoff have been met (see section 5.3). Even so, the low runoff of nitrogen in these years resulted in marked improvements in the quality of coastal waters (see Chapter 8).

The river, Odense Å at Kratholm.

Photo: Bjarne Andresen, Fyn County Council

Nutrient runoff is greatest during the winter half of the year

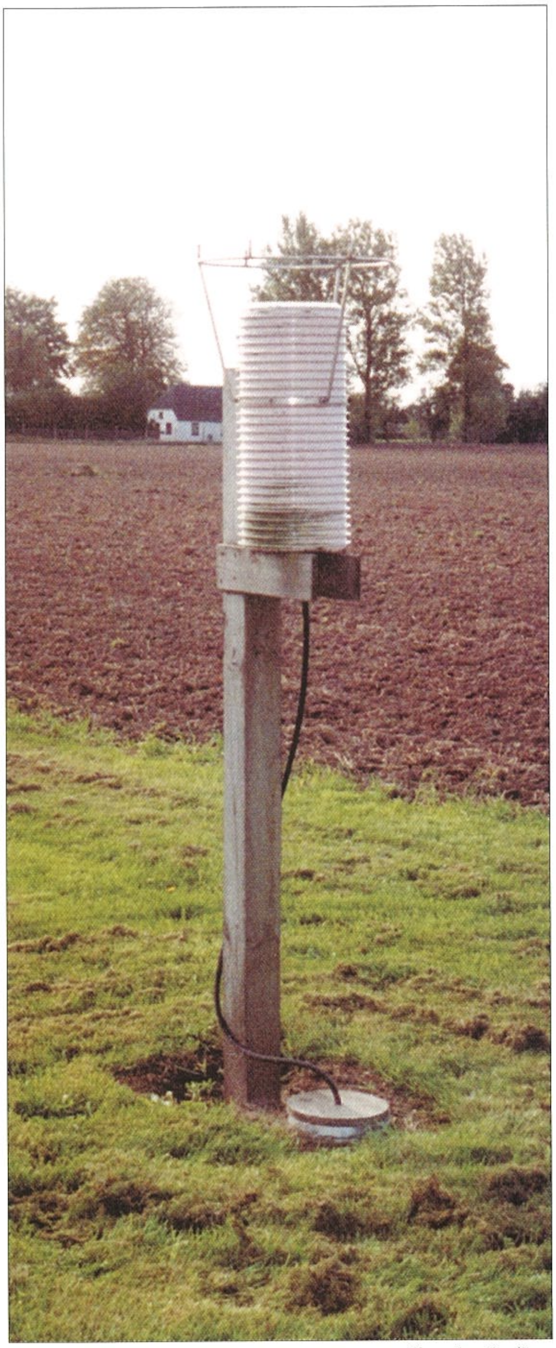
Nutrient runoff in watercourses shows considerable seasonal variation, following water flow in watercourses, soil conditions, drainage, and seasonal variation in precipitation and evaporation. On average, 62% of the annual runoff of nitrogen and 43% of the annual runoff of phosphorus occurs during the winter months December-March. Runoff of phosphorus during the winter months is some 10 times greater than during the summer months. The situation is similar for runoff of nitrogen (Figure 5.2).

Deposition of nutrients

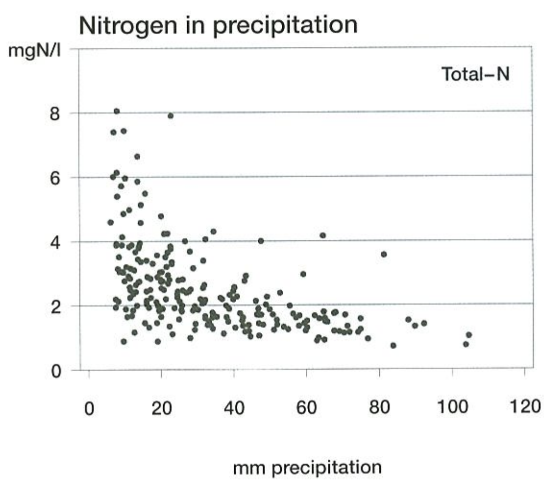
Pollutants in the atmosphere are, sooner or later, deposited to the land or to waterbodies. This occurs either via dry deposition, or wet deposition, i.e. deposition associated with precipitation.

If gaseous nitrogen oxides are considered (see section 5.2), these substances, when in the atmosphere, are gradually converted to nitric acid and nitrate aerosols (where nitrate is bound to water droplets or to solid particles). When deposited via precipitation, this nitrogen is primarily deposited as nitric acid and nitrate aerosols, while in dry periods it is primarily deposited as nitric acid. Gaseous nitrogen oxides are deposited to only a limited extent, and are thus free to be transported over large distances. Thus, only 4% of Denmark's emissions of nitrogen oxides are deposited in Denmark. The remainder is transported to, among other places, Sweden (Statistics Denmark, 1999a). Likewise, emissions of nitrogen oxides from other countries contribute to deposition in Denmark.

If nitrogen emissions occurring as the evaporation of ammonia from agricultural practices (see section 5.3) are considered, ammonia entering the atmosphere will quickly react with gaseous acids to produce ammonium (NH_4) aerosols.



Precipitation measuring station. *Photo: Inge Bendixen, Fyn County Council*



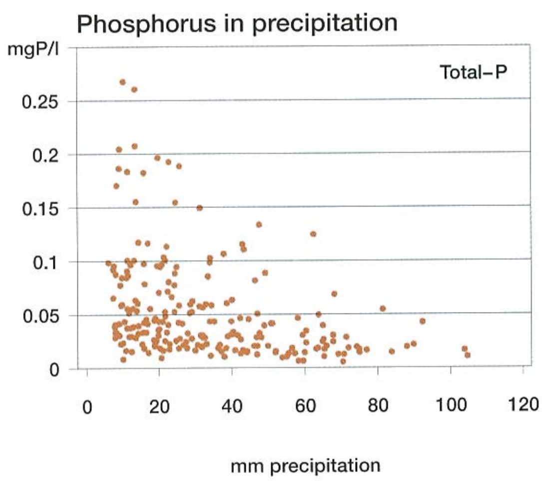


Figure 5.3a Concentrations of nitrogen (Total-N) and phosphorus (Total-P) in precipitation collected at the village of Oure in Fyn County during the period 1989-1999. Nutrient concentrations are shown as a function of the amount of precipitation. Precipitation is collected and analysed at 14-day intervals (bulk sampling).

The evaporated ammonia and ammonium aerosols will only be deposited with precipitation. During dry weather, primarily ammonia gas is deposited. Evaporation of ammonia occurs close to the ground, with the result that between 20% and 60% of the ammonia will be deposited again within a radius of 2 km of the source (Bak et al., 1999). On average, approximately 50% of the ammonia evaporating in Denmark will be deposited inside Denmark. The remainder is transported considerable distances before being deposited in, among other places, the North Sea and Sweden (Statistics Denmark, 1999a). Likewise, farming activities in other countries contribute to deposition in Denmark.

Nutrient levels in precipitation

Since 1989, Fyn County Council has measured nitrogen and phosphorus concentrations in precipitation for the purpose of calculating atmospheric contributions of nutrients to Fyn and its aquatic habitats that are associated with precipitation (Fyn County, 2000a).

Levels of nutrients in precipitation fall as the amount of precipitation rises (Figure 5.3a). This is attributed to pollutants accumulating in the atmosphere in periods of dry weather. Since 1989, the mean annual concentration of total nitrogen in precipitation has been in the range 1.5 - 3.6 mg/l, while the mean annual concentration of ammonia-nitrogen (NH_4-N) has been in the range 0.8 - 1.8 mg/l, and the concentration of nitrogen oxides (NOx-N) has been in the range 0.5 - 1.4 mg/l.

Since 1989, the mean annual concentration of total phosphorus in precipitation has been in the range 0.02 - 0.10 mg/l, and the concentration of inorganic phosphorus has been in the range 0.01 - 0.06 mg/l.

Deposition of nutrients to terrestrial and aquatic habitats

Deposition of nutrients to land is greater than deposition to water (Table 5.2). The relative importance of the deposition of atmospheric pollution depends on the surface area considered. Deposition of atmospheric pollution in open coastal waters is of considerable importance, as their surface area is large in relation to the area of the adjacent land contributing nutrients via runoff. In lakes and fjords, which have a relatively small surface area compared to the land area that drains into them, deposition of atmospheric pollution is of lesser importance than the contribution of nutrients from watercourses and other sources.

On the basis of measurements of wet deposition by Fyn County Council, and literature values for dry deposition of nutrients, atmospheric deposition was calculated to account for 4% of total mean annual input of nitrogen and 2% of total mean annual input of phosphorus to Odense Fjord during the period 1992/93-1997/98 (Figure 5.1). During the summer months, when the flow of water from the land is low, atmospheric deposition is of greater relative importance. Under such circumstances, atmospheric deposition accounts for 13% of the total nitrogen and 4% of the total phosphorus entering the fjord.

Calculated deposition of nitrogen and phosphorus in Fyn County 1999

	Land area kg/ha/yr	Coastal waters kg/ha/yr
Nitrogen:		
Ammonia+ammonium - nitrogen	10.85	9.10
Nitrogen oxides (NOx-N)	12.25	6.05
Organic nitrogen	0.78	0
Total nitrogen	23.88	15.15
Phosphorus:		
Inorganic phosphorus	0.115	0.126
Organic phosphorus	0.084	-
Total phosphorus	0.199	0.126

Table 5.2 Calculated atmospheric deposition of nitrogen and phosphorus to the land area and waterbodies of Fyn County in 1995. The calculated values include both wet and dry deposition (Fyn County, 2000a).

What proportion of the nutrients deposited on Denmark originate from local sources?

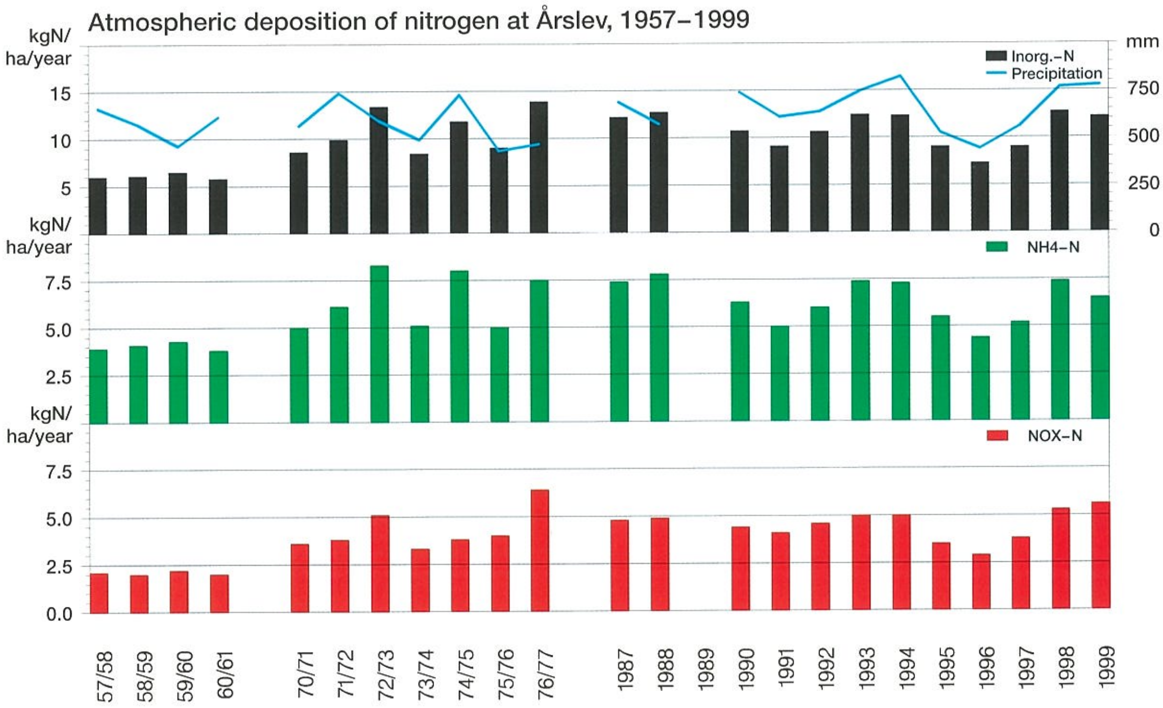
Denmark's land area:

If the total deposition of nitrogen oxides (NO_x) to Denmark's land area is considered, approximately 12% originates from sources in Denmark, while some 88% has its origin in other countries. The reverse is true for the deposition of ammonia-nitrogen, as approximately 77% of the deposited ammonia originates from agriculture in Denmark. The remaining 23% originates from agricultural sources in other countries, notably Germany and the United Kingdom (Statistics Denmark, 1999a).

Denmark's coastal waters:

Some 46% of the total nitrogen deposited from the atmosphere to Denmark's coastal waters in 1998 was in the form of ammonia-nitrogen from agricultural activities (Skov et al., 1999).

Figure 5.3b
Wet deposition of inorganic nitrogen, divided into ammonium nitrogen (NH_4-N) and nitrogen oxides (NO_X-N) in Fyn County during the period 1957-1999. The amount of precipitation at the location is also shown (Fyn County, 2000a). Measurements were made at the villages of Blangstedgård (1957-61, 1970-77) and Årslev (1978-88, 1990-99).



It is difficult, when considering the open coastal waters of Fyn, to compare additions of nutrients via runoff from land and via atmospheric deposition, as the importance of deposition from the atmosphere to the open sea is dependent on the area considered. Atmospheric deposition to the open coastal waters of Fyn is, however, of relatively more importance than to Odense Fjord.

More than 60% of the nitrogen deposited into waterbodies is associated with the deposition of ammonia-nitrogen from farming practices (see also section 5.3).

Trends in the deposition of nitrogen 1957-1999

Measurements show that deposition of nitrogen, both as ammonium-nitrogen and nitrogen oxides, has increased markedly since measurements were first made at the end of the 1950s (Table 5.3 and Figure 5.3b). The rise is due to an increase in energy consumption, an increase in numbers of motor vehicles, and changes in farming practices which have led to greater emissions of nitrogen compounds to the atmosphere.

In recent years, however, there has been a tendency for reduced deposition of both ammonia-nitrogen and nitrogen oxides. This tendency cannot be accounted for by variation in precipitation, but might be explained by reduced atmospheric emissions of nitrogen oxides in Fyn County (see section 5.2) and reduced emissions of ammonia (see section 5.3).

Table 5.3
Wet deposition of inorganic nitrogen, divided into ammonium nitrogen (NH_4-N) and nitrogen oxides (NO_X-N) in Fyn County during several periods between 1957-1999. The amount of precipitation and its pH at the locations are also given (Fyn County, 2000a). Measurements were made at the villages of Blangstedgård (1957-61, 1970-77) and Årslev (1978-88, 1990-99).

	Precipitation mm/yr	pH	NH_4-N kg/ha/yr	NO_X-N kg/ha/yr	Total Inorg. N kg/ha/yr
1957-61	579	4.7	4.0	2.1	6.1
1970-77	576	4.8	6.4	4.3	10.7
1987-88	631	4.8	7.6	4.9	12.5
1990-99	662	5.0	6.1	4.4	10.5

5.2 Households, industry, and traffic

Wastewater

The County's waterbodies receive wastewater from a number of sources. In towns, wastewater is discharged from municipal wastewater treatment facilities that receive wastewater from households and industry via sewers. In addition, 16 larger and smaller factories (> 30 PE, see box to the right) discharge wastewater directly to watercourses or the sea. In rural areas, properties are not typically connected to a sewerage network as the cost is generally prohibitive. In such locations there are many discharges of wastewater from scattered homes to aquatic habitats.

Upgrading of municipal wastewater treatment facilities

Some 85% of the approximately 472 000 people living in Fyn County live in towns. Their homes are connected to the public sewerage network and thus also a municipal wastewater facility. The above figure is a little lower than the average for Denmark, as a relatively large proportion of the population of Fyn live in rural areas. Half of the wastewater received by such treatment facilities comes from households, the other half from industry.

The number of wastewater facilities in the County was greater some 25 years ago than today. Then, the majority employed only mechanical treatment, making them relatively ineffective. Up until 1988, many facilities employing both mechanical and biological treatment, and thus considerably more effective, were constructed. The aim was to improve water quality in watercourses in particular. This was also achieved by concentrating wastewater treatment in larger facilities which discharged directly to the sea. In addition, the direct discharge of wastewater from treatment facilities to lakes in Fyn was abolished.

Between 1988-1994 wastewater facilities in the County were upgraded. This resulted in nearly all large mechanical facilities being replaced by biological facilities, typically capable also of removing nitrogen and phosphorus (Figure 5.4). Consequently, 99% of urban wastewater, equivalent to wastewater from 720 000 PE, is now treated biologically, with additional removal of nitrogen and/or phosphorus. The largest facility, Ejby Mølle in the City of Odense, has a capacity of 268 000 PE. In addition to upgrading, many smaller facilities were closed, so as to concentrate wastewater treatment in a smaller number of larger facilities. Thus, at the end of 1999 there were only 80 municipal facilities in Fyn County.

What is a person equivalent (PE)?

A volume of wastewater can be expressed in terms of the number of people (person equivalents, abbreviated to PE) required, under conditions in Denmark, to produce a volume of wastewater containing the same amount of nitrogen or phosphorus. The size of a PE is, therefore, influenced by cultural conditions and can vary over time. In 2000, a person equivalent, expressed on an annual basis, was equivalent to:

1 PE = 4.4 kg total-nitrogen

1 PE = 1.0 kg total-phosphorus

1 PE = 21.9 kg organic material (BOD_5)

Fyn County Council issues permits for the discharge of wastewater from municipal facilities. The County Council is also responsible for establishing quality objectives for the County's aquatic habitats. In order to meet these objectives, the County Council has set requirements for the quality and amount of wastewater discharged.

As a result of upgrading of the municipal wastewater facilities, discharges of pollutants fell significantly over the period 1988-1999 (Figure 5.5 and Table 5.4). When discharges from 1999 are compared with mean values for the period 1976-1987, it appears that discharges of organic material (BOD_5), nitrogen, and phosphorus have been reduced by 93%, 71%, and 93%, respectively.

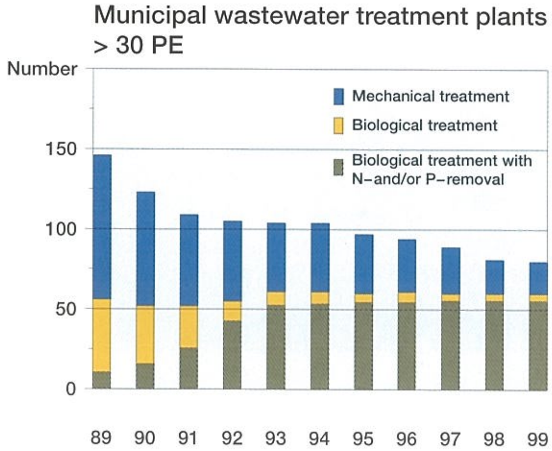


Figure 5.4
An overview of the number of municipal wastewater facilities, and the treatment methods they use, in Fyn County during the period 1989-1999.

Table 5.4
Total amounts and mean flow-normalised concentrations of organic matter and nutrients discharged by the 80 municipal wastewater treatment plants in Fyn County with a capacity of more than 30 PE in 1999.

Discharges from municipal wastewater treatment facilities	BOD_5	Total nitrogen	Total phosphorus
Amounts in discharges (tons/yr)	289	420	33
Mean concentrations (mg/l)	3.2	4.6	0.39

The Action Plan for the Aquatic Environment objectives of an 80% reduction in phosphorus discharges and a 50% reduction in nitrogen discharges have been met for point source discharges since 1992.

How efficient are wastewater treatment plants?

In 1999, all larger wastewater facilities met emission requirements for total nitrogen and total phosphorus, and thus are considered, in general,

Cleansing efficiency at well-functioning wastewater treatment plants in Fyn County

Mechanical wastewater facilities remove only larger material from wastewater. In biological facilities, bacteria degrade the organic material in wastewater, while some of the nitrogen and phosphorus bind to particulate matter that precipitates as sewage sludge. Via the process of nitrification, specific bacteria oxidise the ammonia to nitrate. This makes wastewater less toxic to fish and small aquatic animals. Via the process of denitrification, other bacteria, under anaerobic conditions, convert nitrate to nitrogen gas, that evaporates to the atmosphere. In this way, nitrogen can be removed from wastewater. Phosphorus is removed chemically, by the addition of flocculating agents.

Type of facility and cleaning efficiency	BOD_5 (%)	Total nitrogen (%)	Total phosphorus (%)
Mechanical	35	15	30
Mechanical-biological with nitrification	95	60	50
Mechanical-biological with nitrification and chemical removal of phosphorus	95	60	93
Mechanical-biological with nitrification, denitrification, and chemical removal of phosphorus	95	85	93

Table 5.5
Typical concentrations of organic matter (measured as COD or BOD_5), nitrogen, and phosphorus in stormwater discharges, and total values for such discharges in Fyn County in 1999.

Storm water discharges	COD	BOD_5	Total nitrogen	Total phosphorus
Concentrations of material in discharges from separate sewerage and rainwater systems (mg/l)	50	6	2	0.5
Amounts of material in discharges from separate systems (tons/yr)	792	97	32	8
Concentrations of material in discharges from combined sewerage and rainwater systems (mg/l)	160	33	10	2.5
Amounts of material in discharges from combined systems (tons/yr)	1035	215	63	18
Total stormwater discharges (tons/yr)	1827	312	95	26

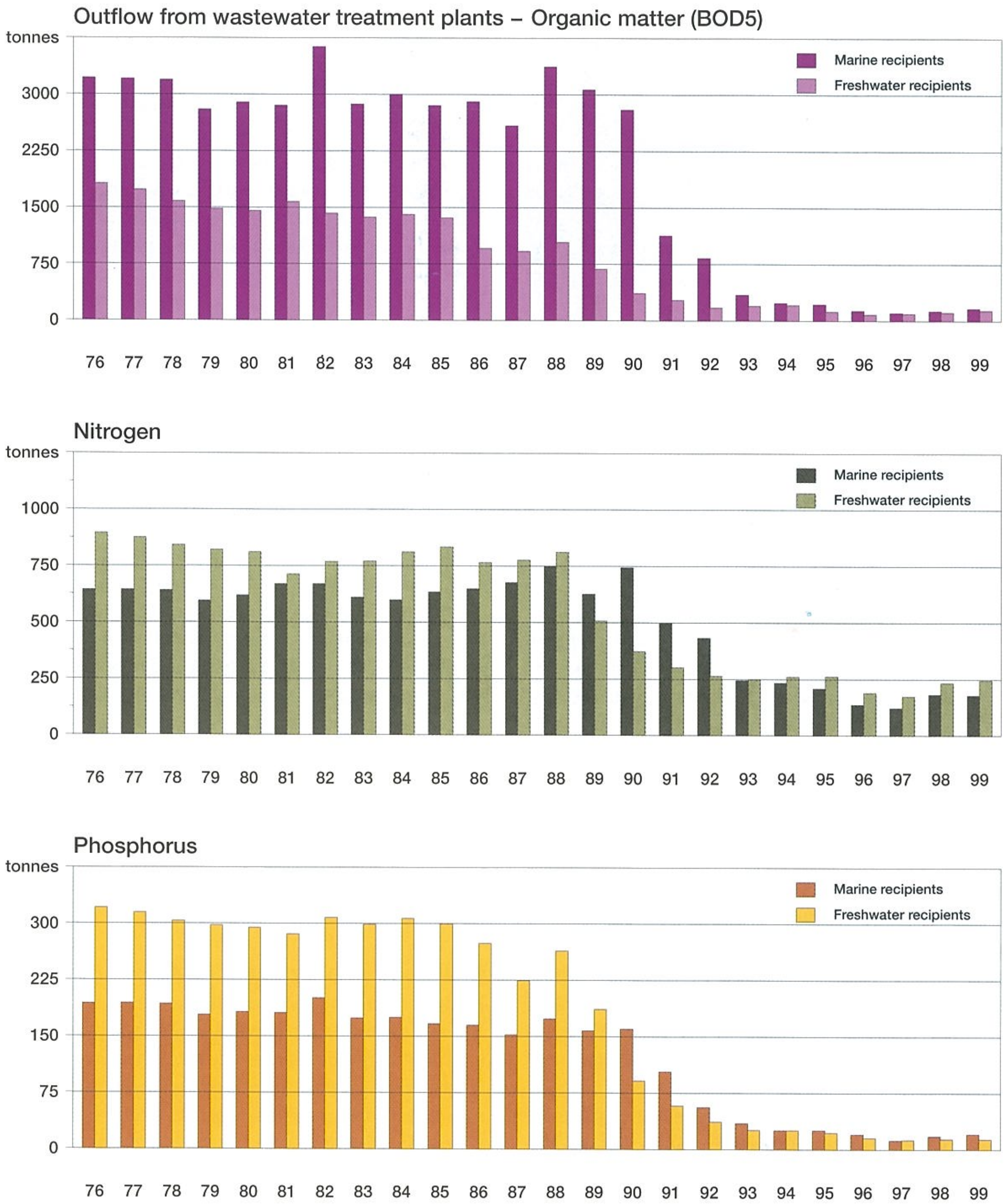


Figure 5.5
Discharges of organic matter (BOD_5), nitrogen, and phosphorus from all municipal and private wastewater facilities > 30 PE in Fyn County during the period 1976-1999.

to function efficiently (Figure 5.6). Two smaller facilities, however, exceeded emission requirements for other substances. Exceeding emission requirements for, e.g. BOD_5 or ammonia has only minor implications for Fyn's coastal waters, but could cause considerable injury to animal life in a watercourse.

Properly functioning wastewater treatment plants with facilities for removing nitrogen and phosphorus are also able to remove a considerable proportion of harmful bacteria from wastewater. Even though some 95-98% of such bacteria are removed, the number of bacteria in effluent wastewater is still considerably higher than the

Discharges from scattered homes	BOD_5 (tons/yr)	Total nitrogen (tons/yr)	Total phosphorus (tons/yr)
Discharges if no form of treatment is performed	1217	245	56
Discharges adjusted for treatment etc.	541	141	32

Table 5.6
Discharges from scattered homes in Fyn County in 1999. The values are calculated based on the number of properties, the average number of occupants per property, and the typical composition of domestic wastewater. Values are given for "untreated discharges" (potential discharges) and for discharges that take account of the treatment efficiencies of various forms of rural wastewater treatment (septic tanks, collection tanks and percolation facilities) set by the Danish Environmental Protection Agency.

Ejby Mølle wastewater treatment plant, Fyn County's largest municipal wastewater facility, with a total capacity of 268 000 person equivalents. The facility treats wastewater from most of the City of Odense. It performs mechanical-biological treatment with removal of nitrogen and phosphorus, followed by filtration. The treated wastewater is discharged to the river Odense Å.

Photo: Gunni Vilhelmsen, Fyn County Council

number permitted in, for example, bathing waters. Thus, the numbers of such bacteria in watercourses that receive even efficiently cleansed wastewater may be so high that there is a considerable risk of infection upon direct contact with the water.

Stormwater discharges

Rain water washes considerable quantities of pollutants into watercourses (Table 5.5). Some are discharged via separate sewerage systems for rain water, that drain roads, paved areas, and the roofs of buildings. Heavy rain results in overflows from sewerage systems that collect both wastewater and rain water (combined sewerage systems). Overflows to, e.g. an adjacent watercourse ensure that wastewater facilities are not overloaded.

In Fyn County, there are some 1 130 discharge points from separate rain water sewerage systems and some 585 discharge points from combined sewerage systems. In 1999, approximately 70% of the nitrogen and phosphorus released in stormwater discharges originated from combined sewerage systems.

Compared with emissions from wastewater facilities in Fyn, stormwater discharges of pollutants are of considerable importance. In 1999, stormwater discharges of BOD_5, total nitrogen, and total phosphorus were 103%, 22%, and 77%, respectively, of the figures for discharges from the County's wastewater facilities. Locally, stormwater discharges can have a considerable effect on the environment in watercourses. In the City of Odense, stormwater can be discharged to the Odense Å at a total of 68 locations. Discharges from these mean that the level ammonia is sometimes so high as to injure fish in the watercourse. Measures have been taken to reduce stormwater overflow to Odense Å.

Untreated wastewater released to watercourses and other waterbodies during stormwater discharges also contains large numbers of pathogenic bacteria, viruses, etc.

Scattered homes

In 1999, some 26 500 homes in Fyn County were not connected to a municipal sewerage system. These properties are located in rural areas. Wastewater from these properties is typically passed through a settling tank, resulting in poorly cleaned wastewater. A total of 83% of the above properties discharge wastewater to an aquatic environment. The remainder allow the wastewater to percolate into the ground or collect it in a sewage tank.

Discharges from these scattered homes can be estimated (Table 5.6). Although only an estimate, their contribution is, without doubt, comparable to that of the County's 80 municipal wastewater facilities (Table 5.4).

Individual industrial discharges

Roughly half of the organic material in wastewater entering municipal wastewater treatment facilities originates from industry. However, the wastewater from a few factories and industrial sites is not sent to municipal facilities. Instead it is treated on-site and discharged directly to a watercourse or the sea (Table 5.7). In 1999, emis-

Table 5.7
Discharges of organic matter, nitrogen, and phosphorus from various industrial facilities and sites to waterbodies in and around Fyn County in 1999. Discharges from the Great Belt bridge are the result of de-icing measures.

Discharges from industrial facilities and sites				
Facility/site	COD tons/yr	BOD_5 tons/yr	Total nitrogen tons/yr	Total phosphorus tons/yr
Danisco Sugar A/S, Assens	40.4	2.5	6.4	0.26
Bågø Aquaculture	-	34.5	5.08	0.55
NKT wire works	-	0.52	2.2	0.011
Fynsværket power station	2.7	0.09	0.23	0.008
Stige Ø waste disposal site	365	26	164	1.5
Great Belt Bridge	-	48.1	0.0005	0.21
Total	408	112	178	2.5

How well do the municipal wastewater treatment plants work?

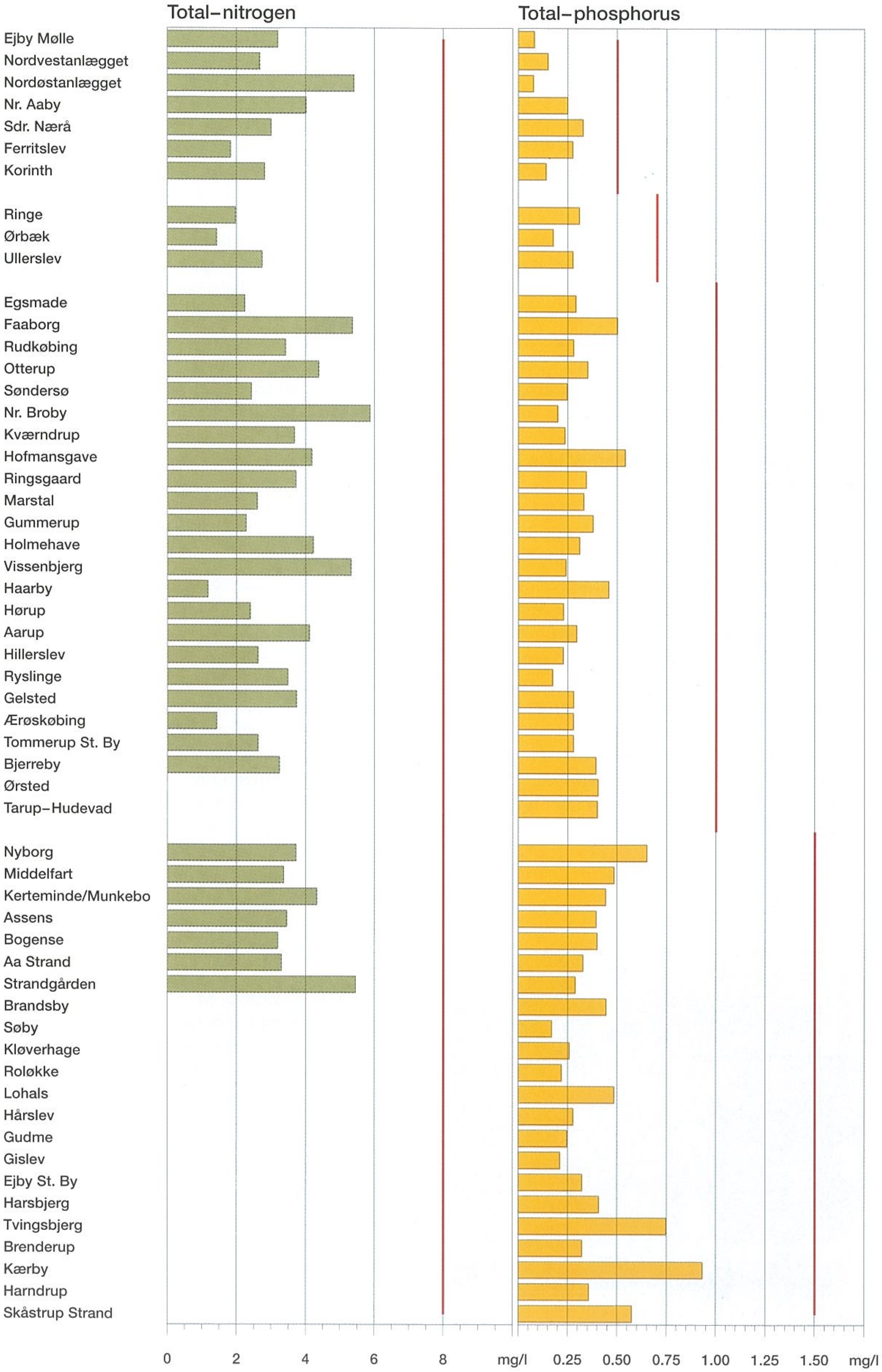


Figure 5.6
Concentrations of nitrogen and phosphorus (measured during inspections) in effluents from large (> 1 000 PE) wastewater treatment plants in Fyn County in 1999. The red lines indicate maximum permitted concentrations in discharges from the various facilities. Discharge limits are also set for a range of other substances (not shown). Discharge limits for nitrogen have not been set of a number of facilities: those for which no data are presented.

sions of BOD_5, total nitrogen, and total phosphorus from these sites combined were 25%, 41% and 6%, respectively, of the figures for discharges from municipal wastewater facilities. Thus, they make a considerable contribution, not least locally. The greatest loads of nutrients originate from the closed Stige Ø waste disposal site, adjacent to the upper reaches of Odense Fjord. Discharges, comprising percolate leaching from the site, are difficult to determine with precision, but are undoubtedly considerable.

Prior to 1995, the greatest polluter was the Danisco Sugar factory in the town of Assens. In 1994-95 the factory constructed its own biological wastewater treatment plant with facilities for removal of nitrogen and phosphorus. Improved treatment of wastewater alone reduced the factory's discharges of organic material, nitrogen, and phosphorus by more than 94%.

Wastewater from controlled waste disposal sites

The majority of today's refuse is disposed of in waste disposal sites constructed with an impermeable base and a system for collecting the liquid (percolate) that collects above this layer. The percolate is cleansed, typically in a municipal wastewater facility, prior to being discharged to the aquatic environment. Such waste disposal sites are controlled to ensure that their loading of the surrounding environment is kept to an acceptable level.

There are five waste disposal sites for normal refuse in the Fyn County. In addition, the firm 'Kommunekemi' has a facility for hazardous wastes located beside the Great Belt.

Photo: Fyn County Council

Some other waste disposal sites, including closed sites such as the Stige Ø waste disposal site beside Odense Fjord, were constructed without an impermeable base or a system for collecting percolate. As a result, percolate from these sites seeps into the aquatic environment. Stige Ø waste disposal site was closed in 1994. A drainage system for collecting some of the percolate generated at the site, and a facility to cleanse it, are planned.

Hazardous substances

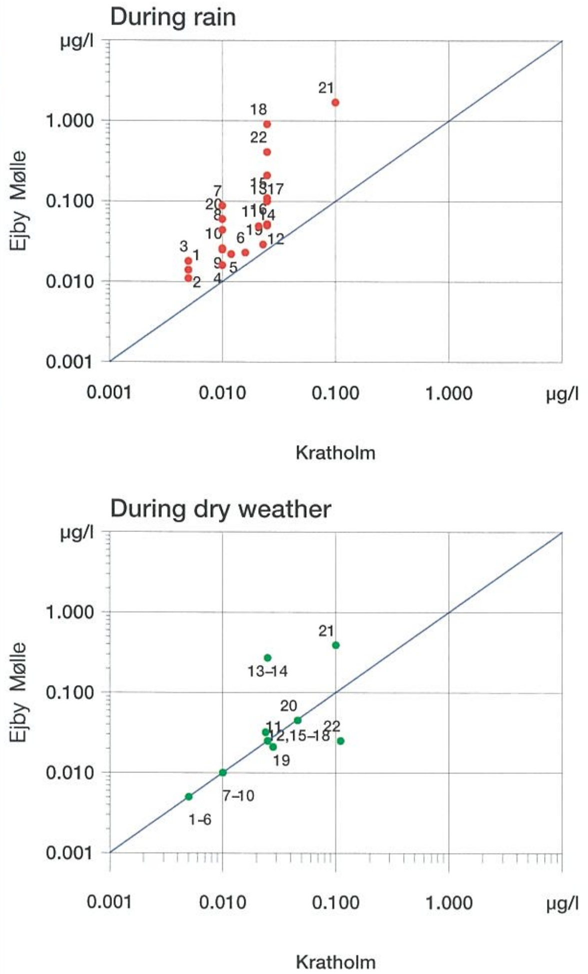
Wastewater is an important source of hazardous substances entering the aquatic environment. The proportion of such chemicals that can be removed during the treatment of wastewater depends not only on the processes operating at the facility, but also to a considerable extent on the properties of the chemicals. Not all substances are readily biodegradable. In addition, chemicals that are poorly biodegradable can, depending on their solubility in water, precipitate out with sewage sludge, bind to suspended particles, or be dissolved in the water phase. Hazardous substances can also be formed in wastewater facilities from other, more complicated, substances.

In 1996, Fyn County Council investigated if 49 selected hazardous substances (comprising nine different groups of substances) were present in the influent, effluent, and sludge from four wastewater facilities located in the City of Odense, in the towns of Faaborg and Nyborg, and at Gislev (Fyn County, 1998a). The highest concentrations in influent were measured in wastewater entering the first three facilities, which receive 60-70% of their wastewater from various factories and industries. The facility at Gislev treats only domestic waste, and so generally receives smaller quantities of hazardous substances. Even at this facility, however, relatively high concentrations of LAS (linear alkyl-sulfonate), in particular, and various "plasticisers" were found, indicating that considerable quantities of hazardous substances are used in domestic settings.

Not surprisingly, considerably lower concentrations of hazardous substances were present in the water discharged from the various facilities. Concentrations of these in discharges from wastewater facilities in the Fyn County are comparable to those reported in other Danish surveys and from Sweden. The substances are either degraded or bind to the sludge generated during the treatment processes.

Sludge from the facilities in Odense and Nyborg had such high levels of certain substances that it could not be spread on agricultural land. At the waste disposal site in northern Odense a composting project has been initiated, in which sewage sludge, garden refuse, and straw is mixed

Hazardous substances in Odense Å at Ejby Mølle (station 9.45) and at Kratholm (station 22.35)



1. **Chrysene/triphenyl**
2. **Indeno(1,2,3-cd)pyrene**
3. **Phenanthrene**
4. **Benz(ghi)perylene**
5. **Pyrene**
6. **Fluoranthene**
7. **Dimethylnaphthalenes**
8. **Methylnaphthalenes**
9. **Tributylphosphate**
10. **Triphenylphosphate**
11. **Naphthalene**
12. **Chloroform**
13. **Nonylphenol (+ethoxylates)**
14. **Nonylphenols**
15. **Nonylphenol monoethoxylates**
16. **Tetrachloroethylene**
17. **Trichloroethylene**
18. **Xylenes inc. ethylbenzene**
19. **Benzfluoranthenes (b+j+k)**
20. **Trimethylnaphthalenes**
21. **Di(2-ethylhexyl)phthalate**
22. **Toluene**

Figure 5.7 Concentrations of selected hazardous substances in Odense Å measured simultaneously at the locations Kratholm (upstream of the City of Odense) and Ejby Mølle (downstream from the stormwater drains in the City of Odense) during rainy and dry weather. During wet weather, concentrations above the detection limits for 22 of 63 chemicals analysed for were measured at Ejby Mølle (downstream location). During dry weather at the same location, nine of the chemicals (4, 6, 11, 13, 14, 19, 20, 21, and 22) were present at concentrations above the detection limit. Chemicals not present at a concentration above detection limits are shown as a concentration half of that of their respective detection limits. For additional information on hazardous substances in river Odense Å, refer to Fyn County (1998a).

and composted. Results to date suggest that it is possible to reduce quantities of harmful substances to levels where the application of such waste materials to agricultural land is acceptable.

In 1997, Fyn County Council made a pilot study of the prevalence of pesticides in the discharge to the Odense Å from the Ejby Mølle wastewater facility. Fourteen of 85 pesticides selected for analysis were found to be present. See Chapter 6 for a discussion of the presence of pesticides in the aquatic environment.

There are apparently also high concentrations of hazardous substances in Odense Å during periods of rain, due to the discharge of untreated wastewater from stormwater overflows in the City of Odense. This was evident in a 1996 survey (Fyn County, 1998a) that detected 22 of 63 foreign substances analysed for (Figure 5.7). One group of substances, the PAHs (polycyclic aromatic hydrocarbons), were present at concentrations (up to 0.029 µg/l) considerably above the permitted level (0.001 µg/l) (Ministry of Environment and Energy, 1996).

What are hazardous substances?

Hazardous substances are toxic, persistent and liable to bio-accumulate and are compounds not naturally found in the aquatic or terrestrial environment. A large and diverse range of products that contain substances considered hazardous substances are marketed in Denmark.

It is estimated that there are some 20 000 chemicals on the Danish market, and that these chemicals are found in some 100 000 different chemical products which, in turn, are used in the manufacture of some 200 000 industrial products (Holten-Andersen et al., 1998).

Hazardous substances are used throughout society, including every day, domestic situations. During production, use, and disposal they are distributed to the air, soil, and water. Thus, every new substance designed and used, will be found in the environment at some point.

Airborne pollution

Burning of fossil fuels (coal, oil products, and natural gas) in power stations generating electricity, municipal power stations supplying warm water, factories and other industrial complexes, commercial greenhouses, households, and in the transport sector (particularly motor vehicles) all contribute to pollution of the atmosphere. This pollution comprises nitrogen and phosphorus, and of many other substances, including sulphurous oxides, that contribute to acidification of rain water (acid rain). The nitrogen emitted by the above sources is primarily in the form of nitrogen oxides (NO_X). Another, well-known pollutant generated is carbon dioxide (CO_2), which traps solar radiation and so contributes to warming of the atmosphere. Industries and waste incineration plants also emit a wide spectrum of other substances that have a range of different effects on the environment.

In 1999, Fyn County emitted 6 200 tons of NO_X-nitrogen to the atmosphere. The primary sources were motor vehicles (2 500 tons) and the 'Fynsværket' power plant (1 600 tons). In comparison, the emission of NO_X-nitrogen for the whole of Denmark in 1997 was 75 000 tons (DEPA, 1999b). Agricultural practices also result in the loss of nitrogen to the atmosphere, though here in the form of ammonia as opposed to nitrogen oxides. Agricultural emissions of nitrogen are slightly larger than the emissions from towns, industry, and traffic combined (see section 5.3).

In 1999, Fyn County emitted some four tons of phosphorus to the atmosphere. The major source was straw burnt in furnaces on farms. Other important sources include the 'Fynsværket' power plant and the burning of straw in larger municipal heating plants.

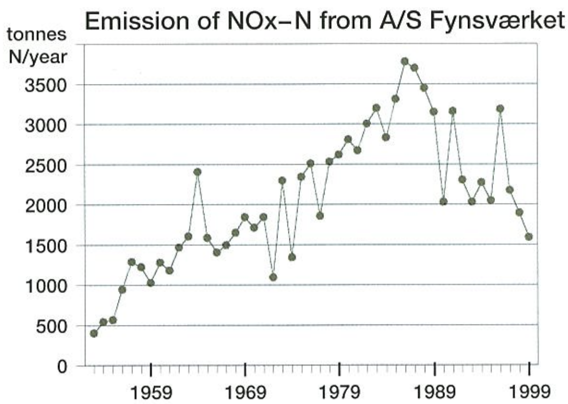


Figure 5.8 Emissions of nitrogen oxides (NO_X-N) in tons/yr from the 'Fynsværket' power plant in the City of Odense during the period 1953-1999.

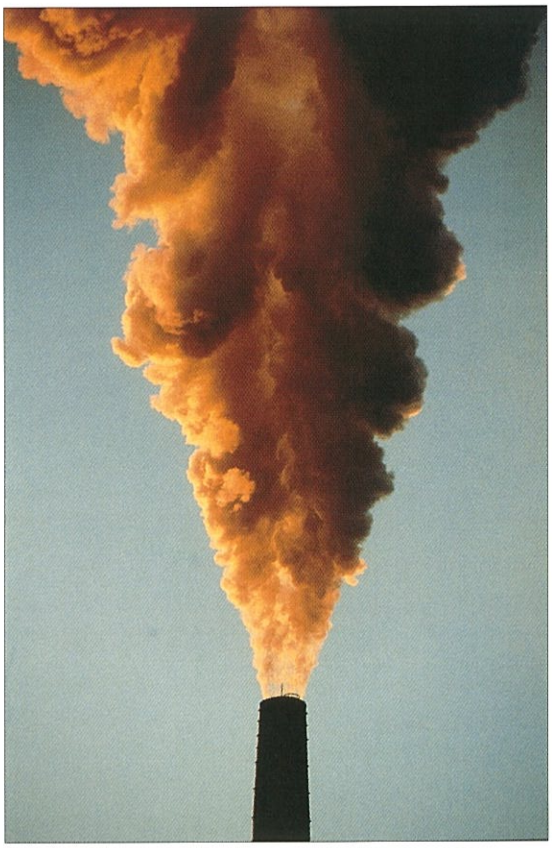


Photo: ThomasWester/Billedhuset

Trends in atmospheric pollution

Emissions of nitrogen, in particular, to the atmosphere from industry and the transport sector have increased in recent decades. For example, emissions from the 'Fynsværket' power plant have risen more than fourfold since 1953, primarily as a result of the County's increased demand for electricity and heating (Figure 5.8). In 1991, the power station began to use a new, more efficient boiler. This resulted in the release of smaller quantities of nitrogen oxides per unit of energy generated, and a reduction in the rate of the increase of total nitrogen emissions. A similar trend, due to the implementation of measures to reduced pollution, is apparent at Danish power stations in general (Statistics Denmark, 1996b).

In comparison, the increase in motor traffic between 1980-90 was accompanied by a 50% rise in emissions of NO_X-nitrogen from this source. From 1990-99, however, emissions from motor vehicles fell by approximately 29%, even though traffic intensity increased by 42% during this period. This is attributed to the requirement that all new petrol-driven motor vehicles registered after October 1990 be fitted with a catalyser.

Refer to section 5.1 for discussion of the deposition of airborne pollutants onto aquatic environments.

Contaminated land

Contaminated land at industrial sites, closed waste disposal sites, and solid-filled gravel pits represent a risk to people living adjacent and poses a threat to the environment. The aquatic environment can be affected by the percolation of contaminants to groundwater and to surface water (watercourses, lakes, and coastal waters).

The threat a contaminated site poses to people and the environment is determined by the contaminant, the manner of spreading and the possibility of exposure of people, animals, and plants.

Some contaminants are relatively harmless, while others require rapid intervention to prevent spreading or exposure of people.

Actions taken by Fyn County Council with respect to contaminated sites are primarily to protect groundwater. Contaminated sites in areas with important drinking water interests, or close to waterworks bore holes, have the highest priority if the contamination includes substances that can spread very rapidly, e.g. chlorinated solvents or petrol.

Recent surveys have shown that a large number of contaminated sites also pose a serious risk to people living on or adjacent to the contaminated sites. Examples include the spread of chlorinated solvents (dry cleaning fluids) from dry cleaners. Such sites also have a high priority.

A particular problem is methane gas produced in closed waste disposal sites. Under certain climactic and geological conditions the gas can penetrate buildings located on or adjacent to such sites, presenting a risk for explosion.

At the end of 1999, Fyn County Council had registered 543 contaminated sites in the County (Figure 5.9), of which half are closed waste disposal sites and half are former industrial sites. The number is expected to rise in coming years as mapping of contaminated sites is undertaken according to regulations in the new Contaminated Land Act.

This new legislation draws together regulations on contaminated soil from the Waste Disposal Sites Act, the Loss of Estate Value Act, and the Environmental Protection Act. At the same time, the coverage of the Contaminated Land Act is broadened to include more recent cases of contamination, diffuse contamination, landfill with waste products, and sites where the underlying groundwater aquifer is at risk.

The Contaminated Land Act also allows differentiation of public efforts with respect to surveys and the cleaning-up of contaminated sites, so that the primary effort can be directed towards contamination that poses a threat to current or future water supply, or poses a health hazard in residential areas, child care facilities, and public playgrounds. Prevention of health hazard and uncontrolled spreading of contaminated soil from contaminated sites is to be ensured by methods other than cleaning up such sites. For example, future efforts by municipal authorities will, in lightly contaminated residential areas, primarily involve advice on how contact with contaminated soil can be prevented.

The primary risks posed to groundwater by contaminated sites in Fyn County are due to chlorinated solvents, petrol, and leachates from closed waste disposal sites. With respect to residential areas, the penetration of vapours from chlorinated solvents and direct contact with, or intake via food, of high concentrations of various heavy metals and tar compounds are the most important problems. For further details see the discussion of Fyn County Council's monitoring of contaminated sites in Chapter 9.

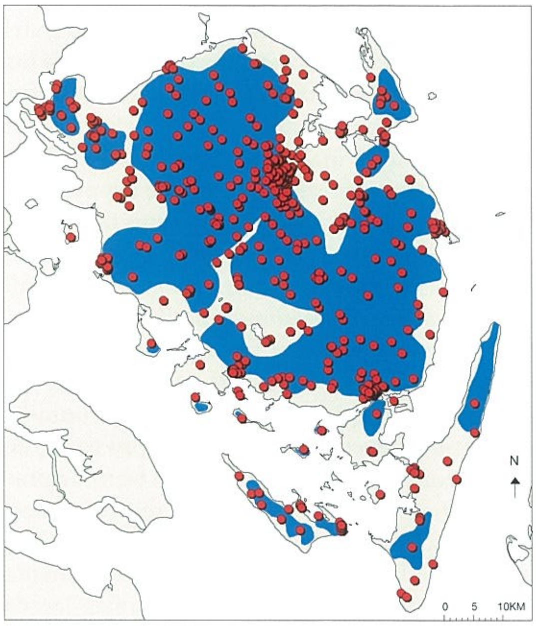


Figure 5.9
An overview of the 543 contaminated sites registered in Fyn County as of 1 January, 2000.

Mapped polluted sites
Drinking water interests

Vesterbro Street in the City of Odense, where contamination from a dry cleaner has resulted in extensive groundwater contamination and the spread of organic solvent vapour to adjacent housing.

Photo: Fyn County Council

5.3 Agriculture

Agricultural activities result in the loss of nutrients and pesticides to the environment. This loss occurs by leaching from farmed land to surface waters and groundwater and by surface runoff to waterbodies. Finally, there are losses to the atmosphere that can subsequently be deposited on waterbodies. Pesticides can also enter the aquatic environment as a result of inappropriate handling or accidents, e.g. in connection with the filling or cleaning of spraying equipment.

This section examines the agricultural practices that are of importance with respect to the loss of nutrients from agriculture to the environment. In addition, developments in emissions to the environment from agriculture, and in farming practices that are of importance with respect to such emissions, are examined, as is the extent to which agriculture has implemented the environmental protection measures required by Danish legislation.

The contribution of agriculture to total emissions of nutrients to the aquatic environment is examined in section 5.1. The importance of agriculture with respect to the prevalence of pesticides in the aquatic environment is discussed in Chapter 6 (Streams) and Chapter 9 (Groundwater).

Agriculture is the most important form of land use with respect to pollution with nutrients. Horticulture and forestry are of far less importance, partly because they cover a much smaller area of land.

In 1999, there were roughly 5 300 farms in the Fyn County. The total area of farm land and land used for horticulture was estimated to be 224 000 hectares, equivalent to 64% of the land area of the County. Horticulture accounted for only 3% of this figure. Approximately 11% of the land area of the County was, in 1999, used for forestry. For further details on land use and historical developments in agricultural practices in Fyn County refer to Chapter 1.

Loss of nitrogen and phosphorus from agriculture to the aquatic environment occurs primarily via leaching from farmed land. Previously, discharges of nutrients from livestock stalls, manure heaps, and slurry tanks resulted in pollution problems, but such discharges have been greatly reduced in recent decades.

Loss of nitrogen to the atmosphere occurs via the evaporation of ammonia from livestock stalls, manure heaps, and slurry tanks, and as a result of the application of animal manure and artificial fertilisers. Approx. 60% of the nitrogen deposited from the atmosphere to waterbodies in and around Fyn was originally lost from agriculture in the County (see Table 5.1 and Fyn County, 2000a).

Leaching of nitrate

Agriculture is the primary source of nitrogen pollution of surface water and groundwater. Since the 1970s, leaching of nitrogen from agriculture to Fyn County's coastal waters has constituted 70-75% of the total amount of nitrogen runoff that, via routes such as streams, enters the sea from Fyn County.

Considerable annual variation in the loss of nitrogen from agriculture is mainly attributable to changing meteorological conditions, e.g. there can be considerable variation between years with high and low precipitation. Greater losses via runoff can also occur in years with poor harvests, e.g. 1992. As a result of the dry conditions in 1995-1996, there was almost no runoff of nutrients from fields in the hydrological year 1995/96. For further details, see section 5.1 on nutrient runoff from Fyn County.

Surveillance by Fyn County Council in selected agricultural areas provides information on the relationship between farming practice and leaching of nutrients to groundwater and watercourses. The investigations include measurement of soil water, drainage water, and groundwater under fields, and measurements in watercourses into which water draining from the fields flows. In addition, landowners are interviewed annually regarding actual farming practices (Fyn County, 2000b).

The investigations show that a range of farming practices have a considerable influence on the size of nutrients losses due to leaching from farmed land. Important practices are the quantity of fertilisers applied, the crops grown, crop rotation, and the handling of animal fertilisers. Meteorological factors, such as the amount of precipitation and the corresponding amount of freshwater runoff in a particular year, are important for how large a proportion of the surplus nitrogen applied to fields is leached from them each year.

Approximately 35-50% of the nitrogen leached from the root zone (the upper metre of farmed land) of fields in clayey soil catchment areas quickly enters watercourses and flows towards lakes and coastal waters (Grant et al., 1998). The remainder of the nitrogen leached from farmed land percolates down to aquifers and subsequently flows into watercourses. During passage from the soil surface to aquifers the nitrogen content of the percolating water is reduced by denitrification.

Leaching of nitrogen from the root zone

Investigations by Fyn County Council in six fields in clayey soils in the County's land mo-

Relationship between agricultural practice and riverine nitrogen runoff

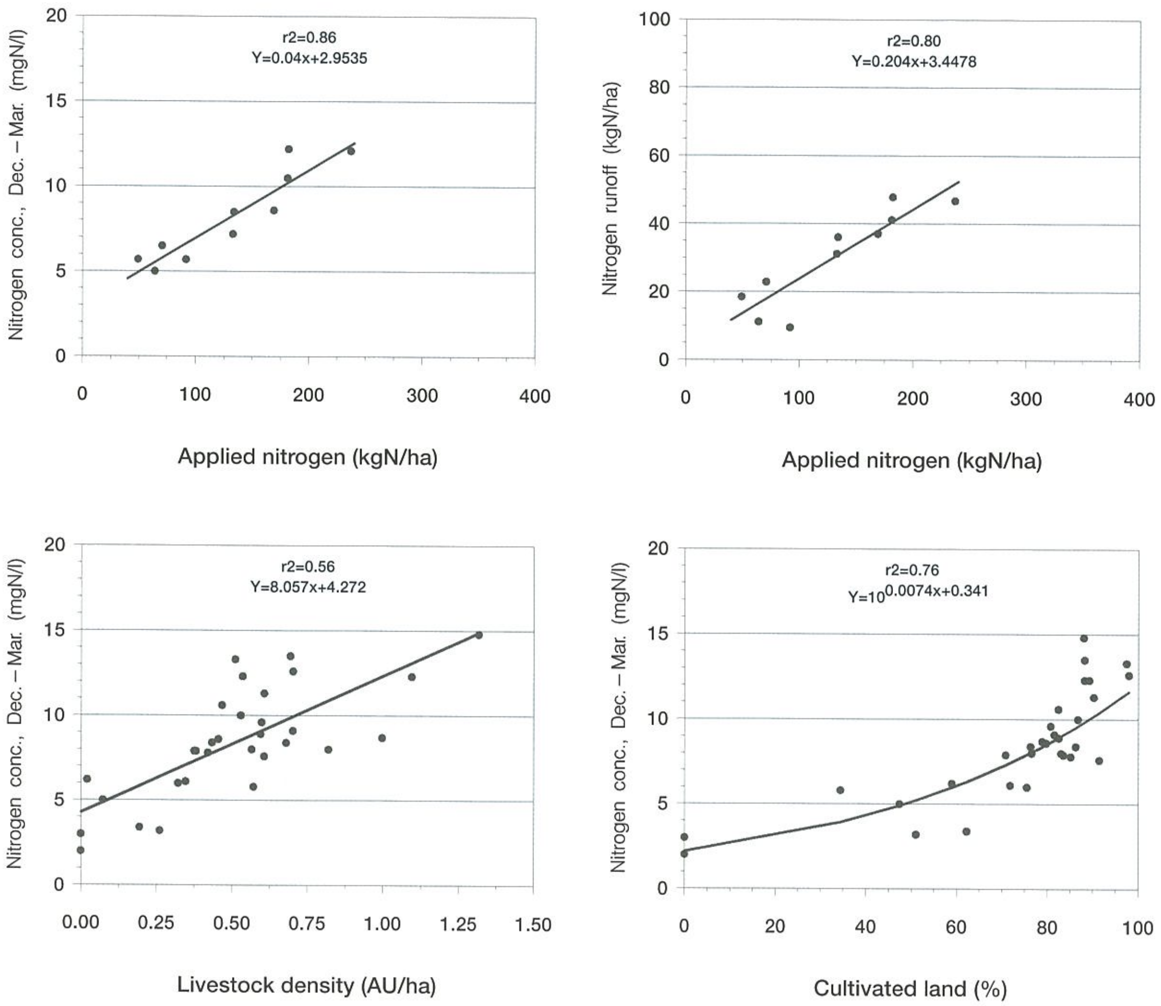


Figure 5.10

Upper:
Nitrogen concentrations (Dec.-March 1993/94) and total runoff of nitrogen (1994) in 10 watercourses as a function of the total amounts of nitrogen fertilisers (kg/ha) applied in the respective catchments. The comparisons are based on water quality data and information on the use of fertilisers in 1993/94 in 10 catchments in the counties of Fyn and Århus (Fyn County, 1997).
Lower:
Nitrogen concentrations (Dec.-March 1993/94) in 31 different watercourses in Fyn County as a function of the density of livestock and the degree of cultivation in the respective catchments.

nitoring areas show that an average of 70 kg of nitrate-nitrogen per hectare is leached from the root zone annually. This agrees with figures for clayey soils examined in other regions of Denmark. Some 25-45% of the total amount of nitrogen applied to the crops is leached from the fields.

The average concentration of nitrate in water leaching from the fields is 19 mg of nitrate-nitrogen per litre. This is equivalent to 84 mg nitrate/l, which is more than three times higher than the guideline upper limit for drinking water of 25 mg nitrate/l.

Leaching increases as the quantity of fertilisers applied increases

The total quantity of nitrogen fertilisers (both artificial and animal fertilisers) applied to a field is the agricultural practice best characterising the extent of agricultural loading of the environment with nitrogen. Thus, in watercourses in Fyn County there is a good relationship between the total amount of fertilisers applied to fields in the catchment areas of watercourses and the amount of nitrogen runoff flowing via watercourses to the sea (Figure 5.10).

Investigations in the County's land monitoring areas show that reducing the quantity of fertilisers applied to fields has a rapid effect on nitrogen runoff. Annual variation in concentration of nitrogen in water leaching from fields generally follows variation in the quantity of nitrogen fertilisers applied to the fields. Reducing the quantity of fertilisers applied to fields will, assuming unaltered meteorological conditions, result in reduced leaching of nitrate already the same year or the subsequent year, though the full effect is first evident after several years.

The highest concentrations of nitrogen in soil water and water draining from fields occur in locations where both artificial and animal fertilisers are applied (Figure 5.11). In such areas the greatest quantities of fertilisers are applied and there is the greatest surplus of fertilisers. Here, surplus means the proportion of the total quantity of fertilisers applied that is excess to the nitrogen requirements of crops.

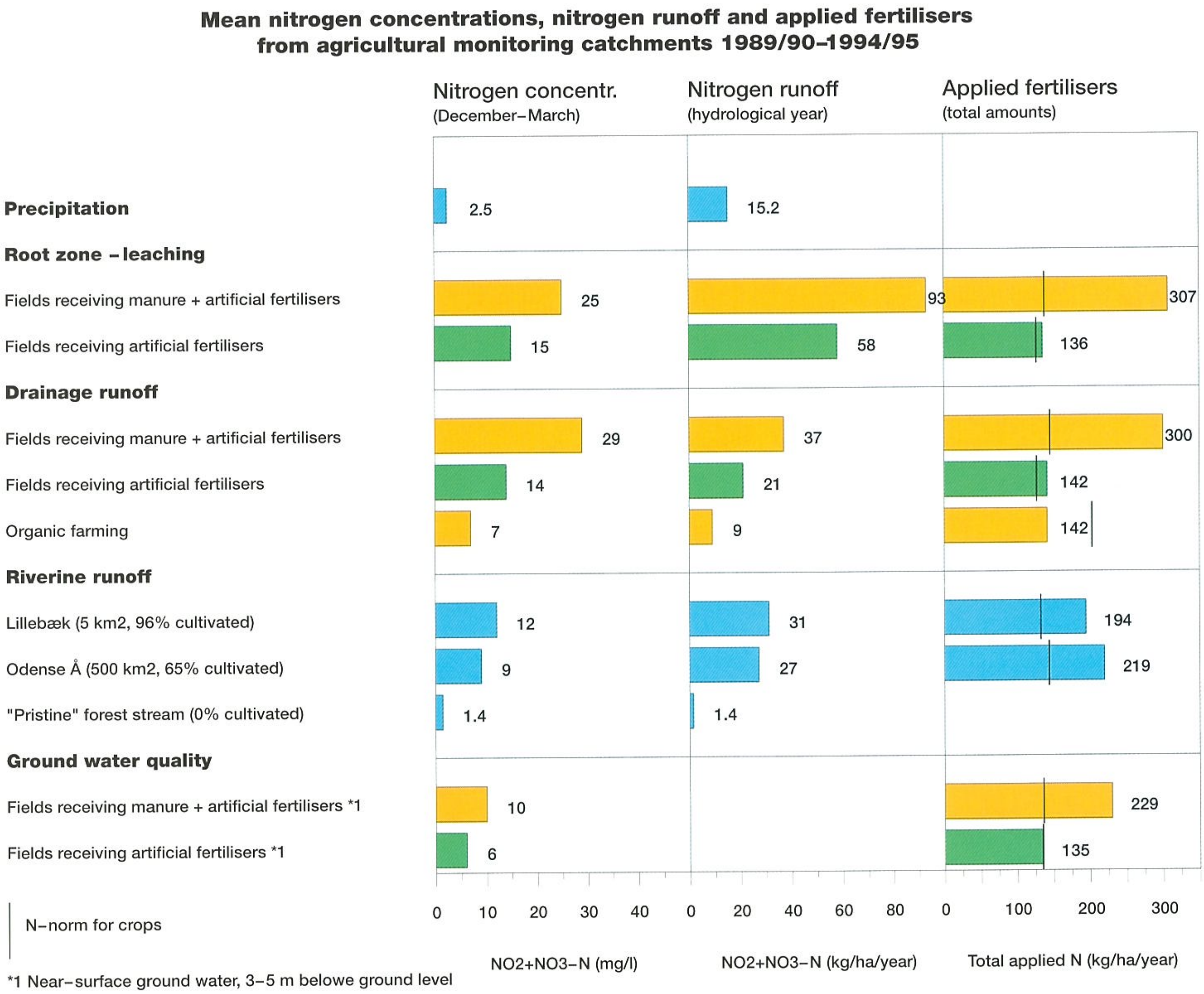


Figure 5.11
Average amounts of nitrogen fertilisers applied to land areas under surveillance, compared to concentrations and amounts of nitrogen in the water draining from the land areas, during the period 1989/90 to 1994/95. Data for the root zone, drains, and watercourses are mean concentrations for the period 1 Dec.-1 April. The nitrogen runoff and precipitation data are mean values for the whole hydrological year. The amount of nitrogen applied is given as mean values for the farming years 1988/89 to 1994/95.

The concentration of nitrogen in watercourses that drain agricultural areas is 8-10 times higher than that in watercourses that drain forests and natural areas.

Leaching of nitrogen also depends on crop selection

Investigations in the land monitoring areas show that the average amount of nitrogen that annually leaches from fields sowed with different combinations of crops varies from 24 to 98 kg nitrogen per hectare. Leaching from winter wheat sowed after leguminous plants averages 98 kg N/ha, whereas leaching from winter cereals and winter rape averages 70 - 74 kg N/ha. Leaching from fields with beet or maize averages 24 kg and 82 kg N/ha, respectively (Fyn County, 1998b).

The extent of leaching from winter corn, winter rape, and maize is considerably greater than expected when it is considered that these crops are designated as 'catch crops' under Danish legislation. Catch crops are considered to have a mitigating effect on leaching, however, this is not the case with those crops that are typically planted.

Potato field. Photo: Henning Bagger/HT-fotografi

Evaporation of ammonia

Evaporation of ammonia (NH_3) via agricultural activities is the primary source of nitrogen lost to the atmosphere as result of human activities, and makes an important contribution to nutrient loading of nature and the aquatic environment (see section 5.1). Urban areas, industry, and motor traffic also emit nitrogen to the atmosphere, though in the form of nitrogen oxides (NO_X) rather than ammonia (see section 5.2).

A recent report on emissions of ammonia from agriculture in Denmark describes the various sources of ammonia evaporation and developments in ammonia evaporation. As of 1996, evaporation of ammonia from agriculture occurred primarily from animal manure (75%), of which evaporation from livestock stalls contributed 32%, manure heaps and slurry tanks 17%, spreading of animal manure 24%, and emissions from grazing animals 2%. The remaining 25% originated primarily from artificial fertilisers and evaporation from crops. The report also states that emissions of ammonia from agriculture fell by 20% during the period 1991-1996 (Andersen et al., 1999).

The magnitude of evaporation of ammonia from livestock stalls depends on the type of stall system. For example, from stalls with deep litter manure evaporation of ammonia is roughly twice as high as evaporation from stalls in which animal waste is collected as slurry (Table 5.8). In addition, evaporation varies depending on the type of animal husbandry, with the least evaporation occurring from production of cattle (Andersen et al., 1999).

Recently, many farms have invested in stall systems with deep litter manure due to the general wish of improving animal welfare. This development will enhance nitrogen loading of the environment due to increased evaporation of ammonia, and to increased nitrogen leaching. The latter is a result of considerably lower utilisation of the nitrogen in deep litter manure than in slurry.

Type of animal manure	Ammonia emissions (kg NH_3-N per 100 kg N in animal manure)		
	Cattle	Pigs	Poultry
Dung and animal urine	24	40	34
Slurry	18	27	23
Deep litter	35	45	47
Deep litter and slurry	27	33	54

Table 5.8
Total evaporation of ammonia from animal stalls, manure piles, slurry tanks, and during the application of various types of animal manure originating from different livestock groups. The values are calculated for the situation in Denmark as of 1996 (Andersen et al., 1999).

Evaporation of ammonia from agricultural activities in Fyn County was estimated to be approx. 8 500 tons NH_3-N in 1997, representing 10% of the total amount of ammonia evaporating from agriculture in Denmark, which was estimated to be approx. 85 000 tons NH_3-N in 1997 (Fyn County, 2000a).

If the amount of ammonia evaporating from Fyn County is compared with the amount deposited to the land area of Fyn, the County is found to have a net export of ammonia of 55% (Fyn County, 2000a). Thus, emissions of ammonia to the atmosphere from agriculture on Fyn County are considerably larger than the atmospheric deposition of ammonia-nitrogen onto the County's land. The land area of Denmark as a whole has a net export calculated to be 43% (Statistics Denmark, 1999a).

Refer also to section 5.1 on atmospheric deposition onto Fyn's land area and aquatic habitats.

Slurry spreading.

Photo: Bjarne Andresen, Fyn County Council

Approximately 25% of ammonia evaporation from agriculture occurs during the spreading of animal manure (Andersen et al., 1999). The use of special equipment (e.g. slide systems or dribble bar systems) can considerably reduce evaporation of ammonia during slurry spreading compared to conventional broad spraying, as shown in this photograph.

Achievement of environmental protection measures by agriculture

Environmental protection measures implemented by agriculture primarily involve limiting leaching of nitrogen and pesticides to aquatic habitats, as discussed in Chapter 2. At present (2000), measures to limit losses of ammonia to the atmosphere and to limit losses of phosphorus from farmed land have been implemented to only a limited extent.

Fall in nitrogen consumption since the beginning of the 1990s

During the period from the mid 1980s to the beginning of the 1990s, the total consumption of nitrogen in artificial fertiliser and animal manure in Fyn County was roughly constant at some 50 000 tonnes nitrogen annually (Figure 5.12). Prior to this period, there was a dramatic increase in consumption of nitrogen during the 1960s and 1970s due to increased use of artificial fertilisers (Figure 1.6).

After 1992, consumption of nitrogen in Fyn County began to fall. From 1992 to 1999 the total consumption of nitrogen in the County fell by 15%, such that roughly 42 000 tons nitrogen have been used annually in recent years. The fall in total consumption of nitrogen fertilisers since 1992 is due to a fall in the use of artificial fertilisers. Between 1992-1999 consumption of artificial fertilisers fell by 23%, from roughly 32 000 to 25 000 tonnes N annually. The primary reasons for the fall in consumption of artificial fertilisers are increased utilisation of the nitrogen present in animal manure and that a portion of County's farmland has been left fallow (8% in 1999) due to obligatory EC demands for set aside areas (EC Agricultural Reform 1992, see Table 2.1a).

The fall in consumption of fertilisers in Fyn County would have had an even greater effect if the production of animal foodstuffs had not increased markedly during the same period (see Figure 1.6).

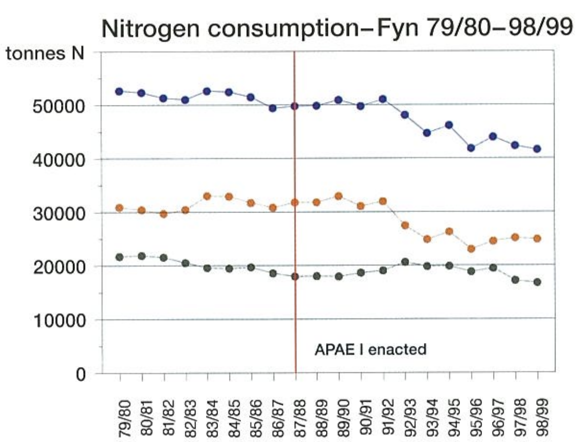


Figure 5.12
Trends in the consumption of nitrogen in Fyn County during the period 1979/80 to 1998/99.

Applied N
N in artificial fertilisers
N in manure

Improved utilisation of animal manure

In order to minimise the surplus of fertilisers in agriculture it is necessary to increase the efficiency of utilisation of animal manure. The degree of utilisation of animal manure indicates the proportion of the nitrogen present in animal manure that crops can be expected to utilise when planning the application of fertilisers.

Legislation set a range of minium utilisation requirements that must be met for the use of different types of animal manure. Requirements for the utilisation of animal manure have been gradually sharpened, most recently in the 1998 Action Plan for the Aquatic Environment II.

In the County's land monitoring areas the average degree of utilisation of animal manure has increased from 32% in 1994/95 to 42% in 1998/99. The average degree of utilisation in 1998/99 was close to the legal minimum requirements for animal manure (see text box on the next page). There is considerable variation in the degree of utilisation between farms, as is also the case for different types animal husbandry.

The proportion of fertilisers applied in the spring is increasing

The point in the year at which animal manure is applied is of primary importance for determining how large a proportion of the nutrients in the fertiliser potentially can be utilised by crops. Thus, the timing of application of fertilisers is also important for how large a proportion of the nutrients in fertilisers are lost to the environment. In previous years, when the majority of animal fertilisers comprised dung and animal urine, it was most common to spread fertilisers on fields in the autumn, when the possibility for utilisation is relatively poor.

With effect from the autumn of 1993, the Action Plan for Sustainable Agriculture prohibited the application of liquid animal manure during the autumn and the winter (with the exception of fields with winter rape and overwintering grass). The pattern of application of animal manure has since changed, so that a progressively greater portion is applied during the spring. In 1998/99, 84% of all nitrogen in liquid animal manure spread in the County's land monitoring areas was spread after 1 February, as compared to only 40% in 1990/91.

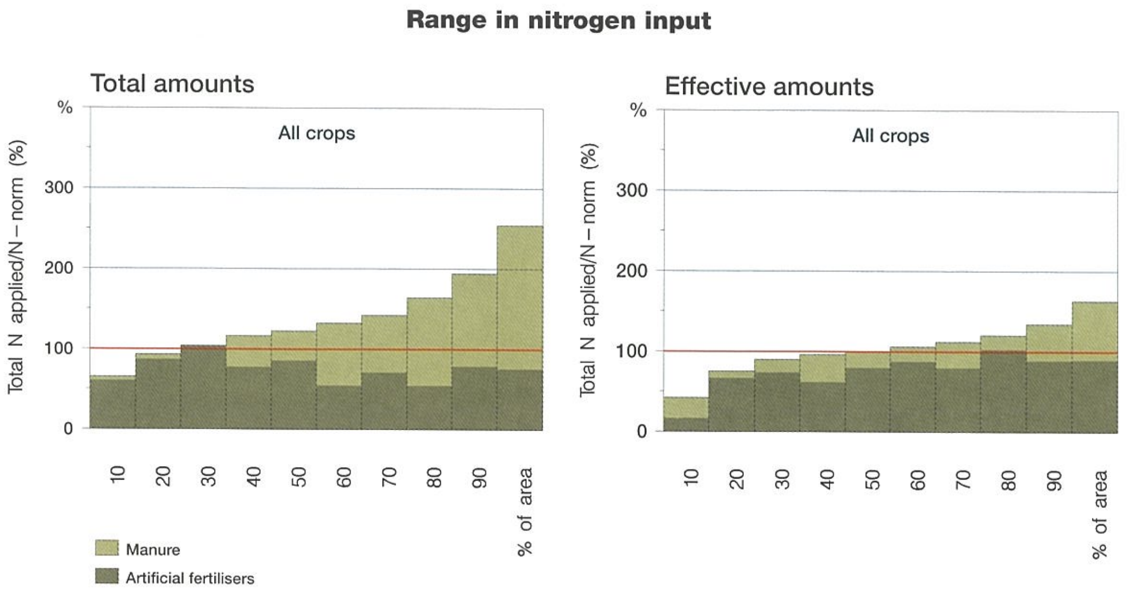


Figure 5.13 Variation in the application of nitrogen to fields in land monitoring catchment areas in 1998/99. Application is presented as total nitrogen and as effective nitrogen, i.e. relative to the nitrogen requirements of crops. Nitrogen requirements were calculated after basic standards laid down in present regulations.

Over fertilisation

The decrease in consumption of fertilisers in the County has meant that the average amount of nitrogen applied to fields has also fallen. This said, many crops still receive considerably more nitrogen than they require.

In the County's land monitoring areas roughly 30% of the agricultural land was fertilised with an amount of effective nitrogen that exceeded calculated nitrogen requirements by more than 20%, and a total amount of nitrogen that exceeded requirements by more than 64% during 1998/99 (Figure 5.13). However, the proportion of the agricultural land in the land monitoring areas supplied with excess fertilisers has been reduced considerably. The quantity of surplus fertilisers applied to the 30% of agricultural land receiving the most fertiliser has been reduced by 20% since the land monitoring programme was implemented in 1989.

Over fertilisation is greatest when animal manure is applied. Crops that commonly receive animal manure (beet for animal fodder and industrial use, and maize) are thus supplied with a considerable excess of fertilisers. Crops such as winter corn and winter rape are, in many cases, supplied with more fertiliser than they require.

Defining "efficacy of animal manure" and "effective nitrogen"

"Efficacy of animal manure" is a value for how large a proportion (%) of the nitrogen in animal manure can be substituted for artificial nitrogen fertiliser.

"Effective nitrogen" is the sum of the amount of nitrogen applied as artificial fertiliser and the amount of nitrogen in animal manure that can be utilised.

The utilisable proportion of nitrogen in animal manure (i.e. its efficacy) is greater when the fertiliser is applied in the spring than in the autumn. Likewise, the efficacy of liquid manure (slurry) is greater than that of solid animal manure. For example, pig slurry applied in the spring by dribble bar systems has an efficacy of 55-65%, equivalent to an amount of effective nitrogen representing 55-65% of the total nitrogen in the slurry.

New separation techniques for liquid manure, capable of "aging" slurry, enable its efficacy to be increased, allowing a reduction in the amount of artificial fertiliser used and the opportunity for a corresponding reduction in leaching of nitrogen from agricultural land. In addition to nitrogen, other nutrients in slurry (phosphorus etc.) can also be utilised more efficiently using these techniques.

Minimum requirements for the utilisation of animal manure

Danish legislation sets out minimum requirements for the utilisation of animal manure by farms. Percent utilisation (utilisation grade) of the animal manure applied to fields describes the extent to which a farm's animal manure is able to substitute for artificial fertiliser in meeting the requirements of crops during the farming year.

Utilisation grade=

$$\frac{(N\ requirement - N\ artificial) \times 100\%}{N\ animal}$$

N requirement:
nitrogen requirements of crops (basic standards laid down in present regulations)

N artificial:
amount of artificial fertiliser applied

N animal:
amount of animal manure applied

Minimum utilisation grade (%)

Year	Cattle slurry	Pig slurry	Deep litter	Other animal fertiliser
1993/1994	40	45	15	30
1994/1995	40	45	15	35
1995/1996	40	45	15	40
1997/1998	45	50	15	40
1999/2000	50	55	20	45
2000/2001	55	60	25	50

Requirements for "green fields" during the winter have been met

The APAE I requirement for 65% "green fields" (i.e. planted) during the autumn months has, in general, been met in Fyn County.

However, "green fields" have not had the expected beneficial environmental effect, as by far the greatest portion of "green fields" are sowed with winter corn, which is not particularly effective in retaining nitrogen during the winter half of the year when runoff is greatest. Loss of nitrogen during the autumn and winter can only be expected to be reduced significantly if fields are covered by well-established plants comprising grasses planted in the spring or other crops that are effective in retaining nitrogen.

Catch crops that are effective in retaining nitrogen during the autumn and winter were present on roughly 11% of the County's agricultural land in 1999. Enactment of the APAE II has sharpened requirements for "green fields" in that at least 6% of the land area sowed with corn, rape, mustard, etc. is required to be subsequently sowed with catch crops as of 1999.

Harmony between livestock production and arable land

In 1999, 23% of livestock farms in the County were not in harmony with regard to the number of livestock and the area of arable land associated with each farm (i.e. the farms had insufficient land to spread optimal levels of the animal manure produced by their livestock). Fyn County is the county in Denmark with the largest proportion of "disharmonious" farms. The disharmonious farms in Fyn have 56% of the County's animal units but only 17% of its arable land (Statistics Denmark, 2000a).

In 1999, the "disharmonious" farms in the County had a deficit of some 22 334 hectares of land, equivalent to roughly 26% of the total area used for animal husbandry. Legislation requires that individual farms have agreements to supply their excess animal manure to other land owners, with the aim of ensuring optimal utilisation of animal manure.

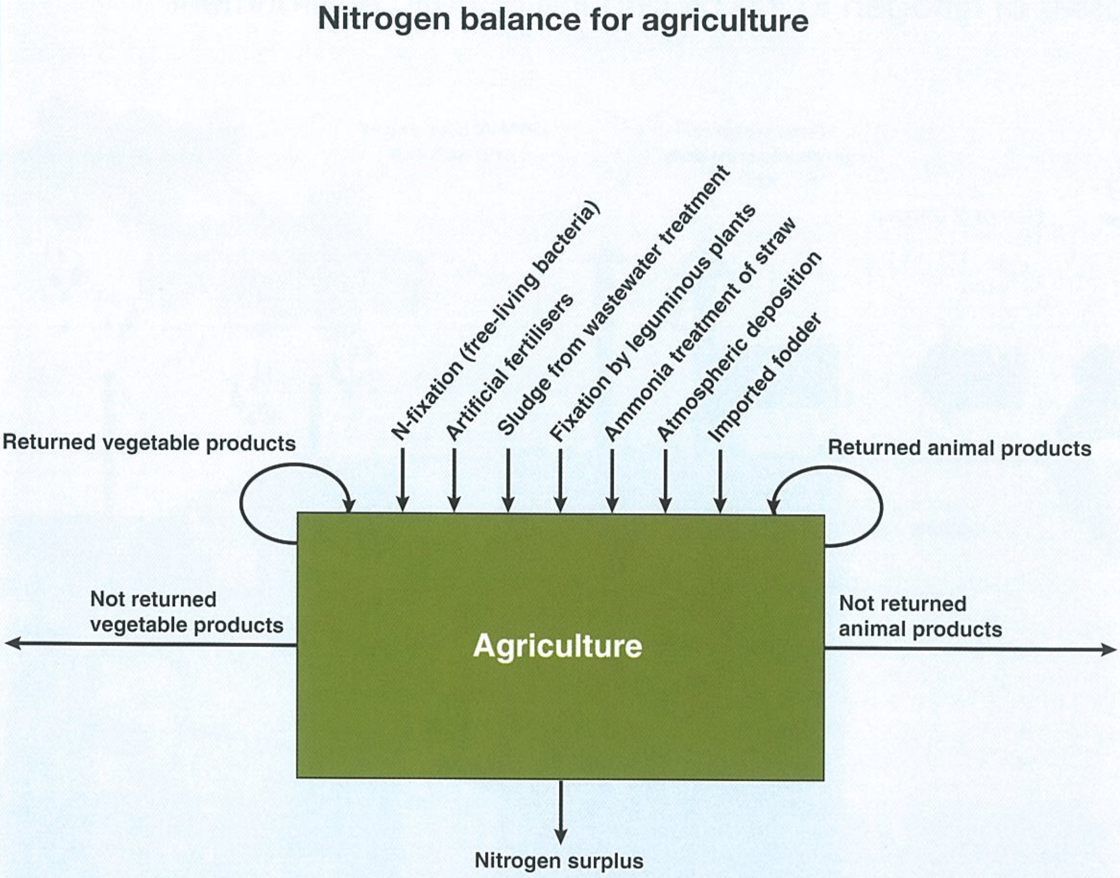
Nitrogen balance for agriculture

Investigations of developments in farming practices in Fyn County and in the County's land monitoring areas both show improvement in the nitrogen balance on farms.

Fyn County Council has drawn up a nitrogen balance for agriculture in Fyn County and in Denmark for the period 1985-1997 (Danedi, 2000). The balance has been presented as an annual account of the consumption of nitrogen by farming activities (artificial fertilisers, fodder etc.) and the export of nitrogen from farms (in the form of products), and calculates the resulting surplus of nitrogen in the individual years.

The nitrogen balance for agriculture shows that during 1995-1997 only one-third of the nitrogen used in agricultural production was incorporated in the products leaving from, or sold by, farms. The remaining two-thirds was surplus to production requirements (Figure 5.14).

The nitrogen balance for agriculture in Fyn County and Denmark shows an improvement in the efficiency of utilisation of nitrogen in the last years of the period investigated. The amount of surplus nitrogen that potentially could be lost to the atmosphere or the hydrosphere was reduced



	Million kgN/year - 3 year moving average					
	Fyn County			Denmark		
	1985-87	1995-97	% change	1985-87	1995-97	% change
Input of "new" nitrogen:	**48.4**	**41.2**	**-15%**	**611**	**525**	**- 14%**
- Artificial fertilisers	31.1	23.9	- 23%	376	288	- 23%
- Fixation	2.2	1.7	- 23%	40	38	- 5%
- Atmospheric deposition	2.4	1.8	- 23%	28	21	- 23%
- Sludge	0.3	0.6	+ 67%	4	9	+ 125%
- Imported fodder	11.6	12.5	+ 8%	154	162	+ 5%
- Ammonia treatment of straw	0.7	0.6	- 16%	10	8	- 18%
Output of nitrogen in products: (excl. returned products)	**12.1**	**14.3**	**+ 18%**	**134**	**168**	**+ 26%**
- Animal products	5.6	7.0	+ 25%	74	90	+ 22%
- Vegetable products	6.5	7.3	+ 12%	60	79	+ 30%
Nitrogen surplus	**36.3**	**26.9**	**- 26%**	**477**	**357**	**- 25%**
Efficiency = (output/input)	**0.25**	**0.35**	**+ 39%**	**0.22**	**0.32**	**+ 46%**

Figure 5.14
Flow diagram and principal figures for a nitrogen balance drawn up for agriculture in Denmark and in Fyn County. The budget is calculated on the basis of data for the period 1985-1997 (Danedi, 2000).

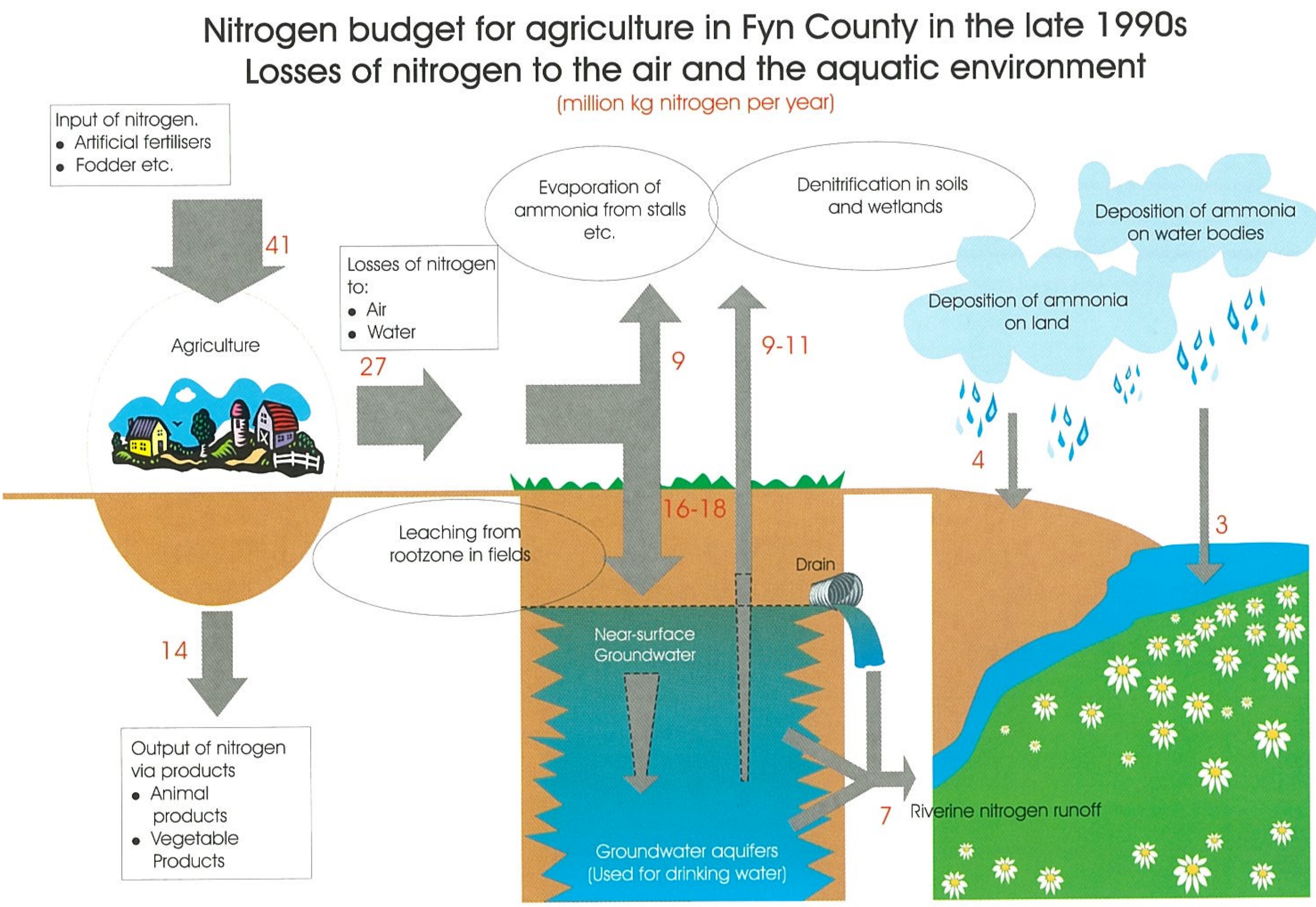


Figure 5.15
A schematic illustration of the nitrogen balance, including the various routes by which nitrogen is lost to the surroundings, for agriculture in Fyn County during the late 1990s. The quantitative flows of nitrogen are based on the results of surveys by Fyn County Council that are discussed in this chapter.

by roughly 25% in the ten-year period up until 1997, both in Fyn County and in Denmark as a whole.

It has been assessed that the reduction in surplus nitrogen in agriculture must be around 50% in order to meet the politically-agreed objectives for reducing the loss of nitrogen from agriculture to the aquatic environment.

It is difficult to precisely determine the proportions of the surplus nitrogen lost to the atmosphere and hydrosphere, respectively. Based on various investigations during the mid 1990s it can be estimated that roughly one-third of the nitrogen surplus is lost in the form of evaporation of ammonia to the atmosphere and two-thirds is lost to the hydrosphere. Around half of the loss to the hydrosphere is denitrified before reaching groundwater, watercourses, and coastal waters (Figure 5.15).

A recent review of emissions of ammonia from agriculture (Andersen et al., 1999) states that emissions from agriculture in Denmark fell by roughly 20% during the period 1991-1996.

If, as mentioned previously, the total surplus of nitrogen in agriculture was reduced by roughly 25% during the 10-year period up until 1997, it is reasonable to assume that the proportion of the surplus nitrogen entering the hydrosphere has also been reduce by some 25%. It is estimated that roughly half the nitrogen lost to the hydrosphere is denitrified, though no measurements have been made to determine the extent to which denitrification has changed with time, as is discussed at the end of this chapter.

If the reduction in ammonia emissions from agriculture to the atmosphere is less than assumed, the reduction in the loss of nitrogen to the hydrosphere will be relatively greater, assuming the amount of nitrogen in the nitrogen balance is unaltered.

Increased livestock production and improved animal welfare can increase loading of the environment

An increase in animal production in the County has reduced the effectiveness of environmental measures taken in agriculture in recent years. All other things being equal, an increase in animal production will increase the total nitrogen loading of the County's agricultural land and thus also of its aquatic environment.

During the last 10 years, animal production in the County has increased markedly (see Chapter 1). The production of pigs, in particular, has shown a marked increase, whereas the number of cattle has fallen. Fyn County is one of the counties in Denmark in which there has been the greatest increase in the pig population over the last 10 years (Statistics Denmark, 2000a).

Production of animal protein (meat, milk, and eggs) in Denmark and Fyn County increased by 22-25% during the 10-year period up until 1997 (Figure 5.14). It is assessed that if this increase in production had not occurred, the reduction in the agricultural surplus of nitrogen would have been around 40% in the 10-year period (compared with the actual figure of 25%). The increase in animal production has negated a considerable part of the gains achieved as a result of investments to improve the efficiency of agriculture and its impact on the environment (Danedi, 2000).

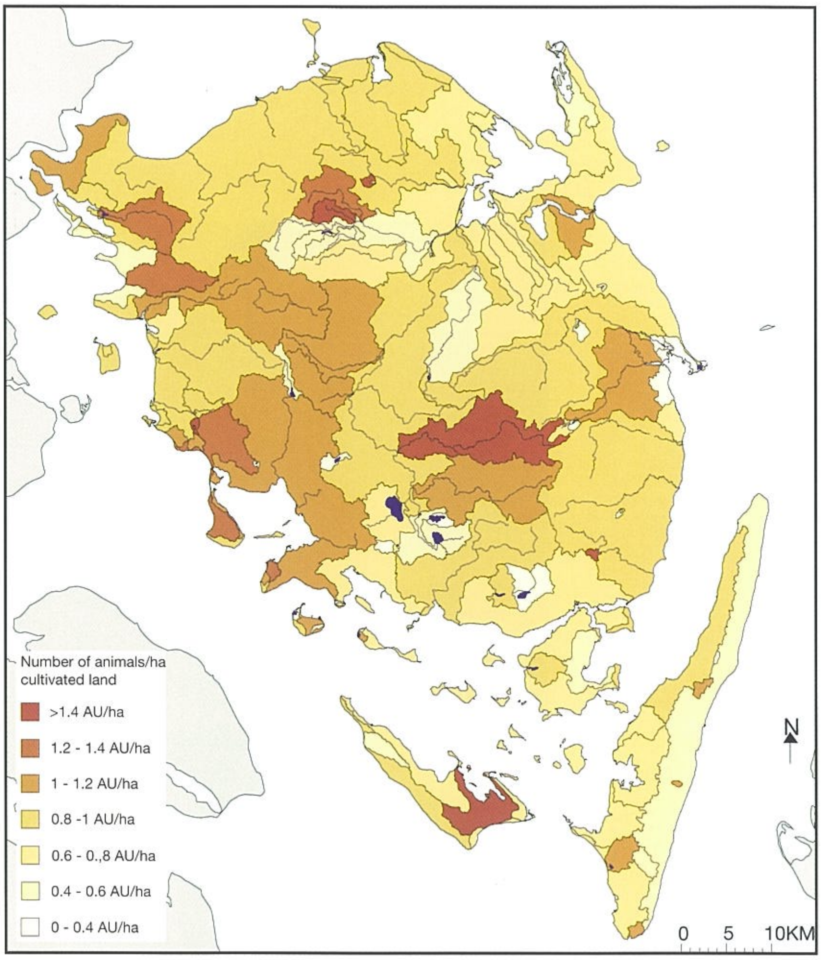
It can be calculated that a pig farm that increases its production from 100 to 320 animal units will increase the annual amount of nitrogen leached (from fields) by an amount equivalent to the amount of nitrogen present in treated wastewater from roughly 14 000 people. Some 35-50% of this nitrogen, equivalent to that in treated wastewater from 5 000-7 000 people, will enter watercourses and thus pollute lakes and coastal waters. The remainder percolates from agricultural land towards aquifers. The nitrogen concentration in the percolating water is reduced by denitrification. How large an amount reaches aquifers depends on the reduction capacity of the overlying soil (see Chapter 9).

Livestock density in Fyn County averages about 0.9 animal units (AU) per hectare of arable land, though there is considerable variation from area-to-area. In certain catchment areas the density is more than 1.4 AU/ha, while in others it is less than 0.5 AU/ha (Figure 5.16). This large variation within the County results in considerable variation in leaching of nitrogen and in the evaporation and deposition of ammonia onto terrestrial and aquatic habitats.

It could be claimed that there is room for a 40-70% increase in animal production in the County according to the harmony regulations established in Denmark in pursuance of the EC Nitrate Directive. Thus, current legislation allows the possibility that the beneficial environmental effects of the measures implemented in accordance with the APAE I and II can be partly or totally negated as a consequence of greater nitrogen and phosphorus loading of the environment due to an increase in animal production.

Other factors, such as improved animal welfare and cultivation of crops that require greater amounts of nitrogen, can also contribute to increasing the load on the environment. Currently, there is a trend towards the use of more animal-friendly stalls. These systems result in animal manure in a form for which the utilisation re-

Distribution of livestock



Source: The Central Livestock Register, March 1999

Figure 5.16
Density of livestock in the catchments of watercourses and local waterbodies in Fyn County. The figure shows the number of animal units (AUs) relative to the area of agricultural land in the catchment (AU/ha), based on data for March 1999 from the Ministry of Food, Agriculture, and Fisheries. The total area of agricultural land in the County is calculated to be 224 000 ha, and some 218 000 animal units are registered.

Outdoor pig production. *Photo: Henning Bagger/Nordfoto*

During the last decade the number of sows living outdoors has increased considerably, partly because of the potential of the outdoor system to allow sows to behave naturally.

Vodrup Klint on the island of Ærø.

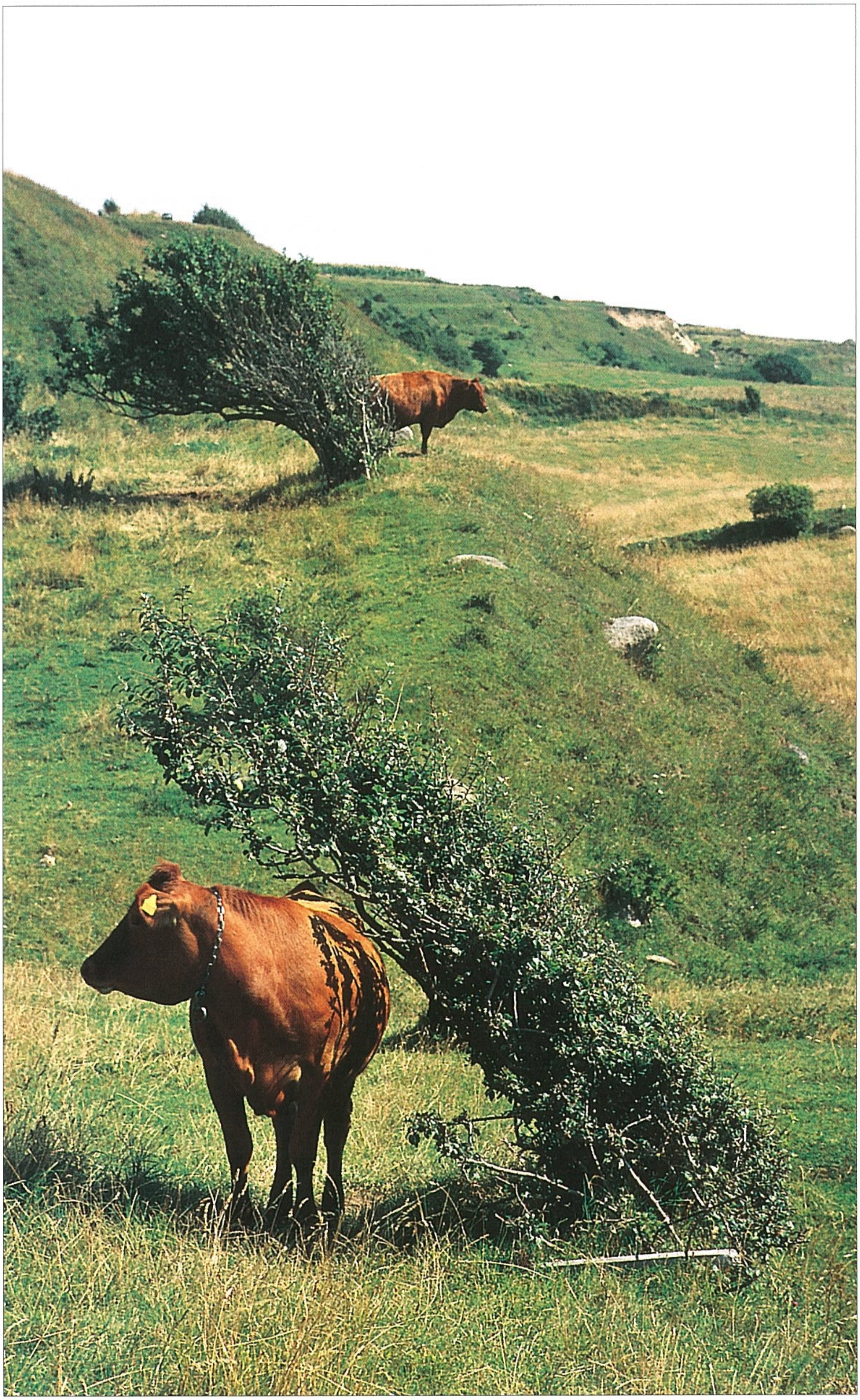


Photo: Birgit Bjerre Laursen, Fyn County Council quirements for nitrogen are lower and, as a consequence, the loss of nitrogen to the atmosphere and hydrosphere is greater.

Agreements on environmentally friendly farming in special selected areas

As a result of implementation of the EC agricultural reform from 1992, the counties in Denmark have identified agricultural areas where environmental subsidies are possible. Fyn County Council has identified approximately 48 000 ha farmland (21% of the agricultural area) as specially environmentally sensitive areas (ES areas). In identifying these areas, stress has been placed primarily on areas with important groundwater reservoirs and areas suitable for restoration or conservation of wetlands as nitrate filters.

In the ES areas it is possible to enter a number of different agreements designed to conserve and enhance the environmental and natural values of the land. It is voluntary for farmers to make agreements in ES areas. The ES area agreement holders receive an annual payment in return for adopting these measures. In 1999 these agreements covered approximately 5 900 ha or 2.6% of the County's agricultural area (table 5.9). Agreements are set for 5 and 20 years.

Re-creation of wetlands

As part of the APAE II, Fyn County Council has, since 1998, administered environmental schemes for the permanent re-creation of wetlands with the aim of reducing the nutrient loads entering surface waters. By 2004, agriculture in Denmark must have re-created 16 000 hectare of wetlands, of which 1 600 ha are in Fyn County. Wetlands are re-created by entering into optional, permanent agreements with economic compensation to the landowner.

Experimental projects show that wetlands have the potential to transform 350 kg of nitrogen per hectare. During the last 10 year Fyn County Council has made experimental projects involving the re-creation of wetlands to increase the transformation of nutrients.

As of the end of 1999, the wetlands project in the County that is part of the APAE II was not completed. As of the middle of 2000, preliminary investigations of some 945 ha of potential wetlands have been approved in the County. Preliminary investigations have been made at roughly 760 ha, at which both technical and ownership aspects have been examined.

Time will show to what extent it is possible to enter into agreements with the property owners concerned, and if the projects for which preliminary investigations have been made can be realised.

Agreements regarding more environmentally friendly farming practices

Agreement	Area covered (hectares)
Environmentally friendly management of pasture	ca. 2600
Maintenance of pasture and natural areas	ca. 1300
Altered drainage practices	ca. 1000
20-year fallow period for agricultural land (set aside)	ca. 580
Reduced application of nitrogen	ca. 220
Farming without pesticides etc.	ca. 40
Catch crops in cereals	ca. 160
Spray-free buffer zones (pesticides)	ca. 2650 m
Total (hectares)	ca. 5900

Table 5.9
Agreements signed regarding more environmentally friendly farming practices in Fyn County during the period 1995-1999.

A re-created wet meadow for nutrient transformation on Rødkilde Estate, southern Fyn.

Photo: Poul Rasmussen

Trends in nitrogen runoff from agriculture

In section 5.1 it was stated that it has been assessed that land-based nitrogen runoff from Fyn County has been reduced by some 20-25% since the APAE I was adopted in 1987. A reduction of about 10% is attributed to improved wastewater treatment, with the reduction in nitrogen runoff from agriculture accounting for the remaining 10-15%. Thus, there is still a long way to the objective of a halving of nitrogen emissions.

As mentioned previously, the nitrogen balance calculated for agriculture in the County for the 10 years up until 1997 shows that losses of nitrogen have been reduced by roughly 25%. It was also assessed that about one-third of the surplus is lost via evaporation of ammonia to the atmosphere, about one-third is denitrified - and thus lost to the atmosphere as free nitrogen (N_2) - as leached nitrogen percolates towards aquifers, while the final one-third of the surplus finds it way to watercourses and other surface water.

It is not automatically the case that a 25% reduction in surplus nitrogen will result in a corresponding reduction in the amount of nitrogen runoff in watercourses. Trends in the loss of nitrogen to the atmosphere (evaporation of ammonia) and in the extent of denitrification also play a role. Additionally, changes in the pools of organic and inorganic nitrogen in soil can play a role.

In the following text trends in nitrogen runoff from agriculture are assessed on the basis of measurements of nitrogen runoff in watercourses in the County. The values are normalised for the effects of annual variation in precipitation and freshwater runoff.

Nitrogen runoff increased in the 1960s and 1970s

Developments in the amount of nitrogen entering watercourses in Fyn follow trends in the consumption of nitrogen fertilisers (Figure 5.17).

During the period from the mid 1960s to the mid 1970s there was a statistically significant increase in flow-normalised nitrogen runoff in the Odense Å. The rise represents an annual increase in nitrogen runoff of roughly 1 kg nitrogen per hectare catchment area, or an increase of about 50% in the amount of nitrogen runoff in the watercourse.

During the period from the end of the 1970s to the beginning of the 1990s annual, flow-normalised nitrogen runoff in the watercourse was roughly constant, a trend mirroring the consumption of nitrogen fertilisers.

Relationship between consumption of fertiliser and nitrogen runoff

Environmental protection measures implemented on farms in Fyn County during the period 1992-1999 have resulted in the consumption of nitrogen fertilisers falling by some 15%, from roughly 50 000 tons at the beginning of the 1990s to a level of about 42 000 tons in recent years (Figure 5.12 and 5.17).

Investigations in the land monitoring areas in the County identify a relationship between the total amount of nitrogen fertilisers applied in catchment areas and nitrogen runoff in the respective watercourses (Figure 5.10). On this basis, it is assessed that the trend for a reduction in use of fertilisers in the County will result in an

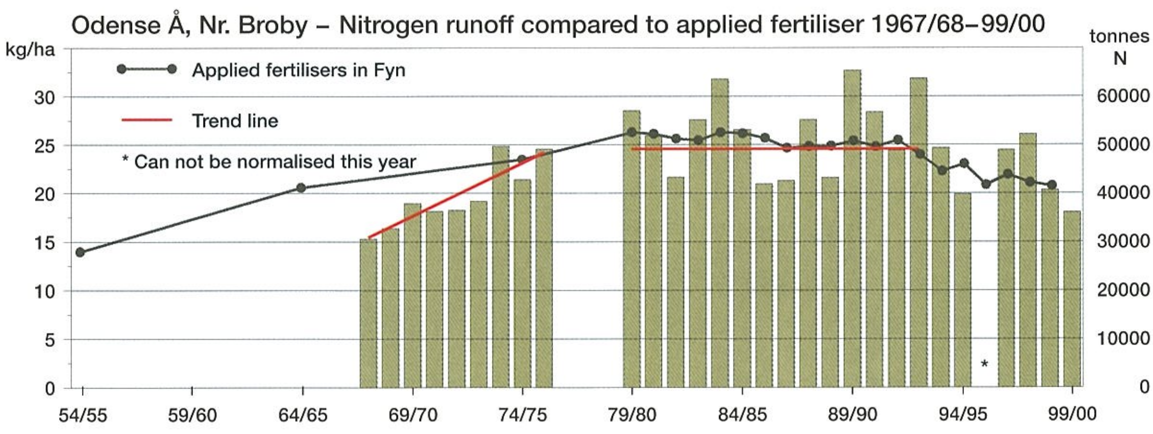


Figure 5.17 Flow-normalised runoff of nitrogen (nitrate-N, kg/ha) measured in Odense Å at the location Nr. Broby during the period 1967/68 to 1999/00, and the consumption of nitrogen fertilisers (tonnes N) in Fyn County during the period 1955/56 to 1998/99.

Drain outlet.

Photo: Bjarne Andresen, Fyn County Council

Most of the nitrogen and phosphorus emissions from agricultural reach surface waters via drains. Drainage of agricultural areas reduce the retention capacity of soils and increase emissions from agricultural areas. A low drainage percentage of cultivated lands and a high percentage of wetlands in catchment promotes a high retention capacity.

expected reduction in agricultural nitrogen runoff in watercourses of 10-15%. Such a reduction is equivalent to an estimated reduction in leaching of nitrogen from fields of the same magnitude.

Nitrogen runoff in watercourses has not declined significantly

Statistical analysis of trends in normalised diffuse nitrogen runoff measured in streams do not show a statistically significant decline in runoff since the APAE I was adopted in 1987. The measured flow of nitrogen in watercourses was normalised to account for emissions of wastewater and the volume of freshwater runoff in the particular year. Even after this adjustment of the measured flow of nitrogen there remains sufficiently large annual variation in the available time-series, due to varying meteorological conditions, that it will be many years before a decrease in runoff in watercourses of 15% could be shown with statistical certainty.

During the recent hydrological years, 1998/99 and 1999/00, flow-normalised runoff of nitrogen in watercourses in the County was an average of 13% and 23%, respectively, below the level prior to enactment of the APAE I (Figure 5.18).

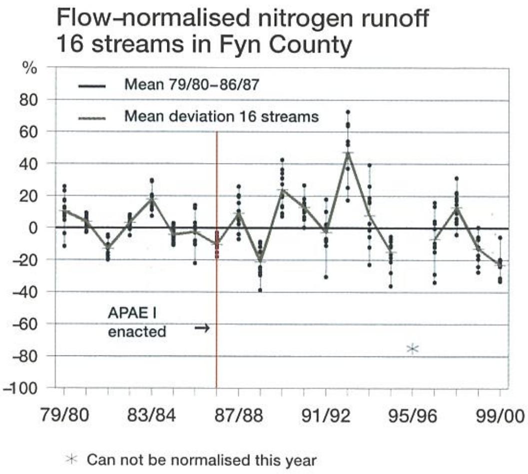


Figure 5.18
Diffuse runoff of nitrate-nitrogen (flow-normalised) in 16 watercourses in Fyn County during the period 1979/80 to 1990/00. For each watercourse the flow of nitrogen is shown as the percentage difference between flow for the particular year and the mean flow of nitrogen prior to enactment of the Action Plan for the Aquatic Environment. Measurements are adjusted to account for the addition of wastewater to the watercourses.

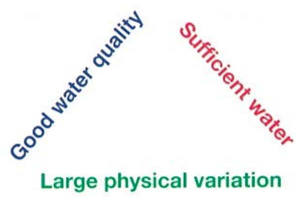
Kongshøj Å at Lunde Bro. *Photo: Stig Eggert Pedersen, Fyn County Council*

6 Streams

There are presently approximately 3 400 km of open watercourses in Fyn County. These watercourses flow through a predominantly cultured landscape. The landscape is varied, ranging from flat heath lands to hilly areas, and the soils are dominated by clayey soil types. As a result of these natural conditions, streams in the County, especially in their lower reaches, have a larger slope and a correspondingly greater mean velocity than are typical for the majority of Danish streams. The dominance of clayey soil types means that water flow is poor during the summer months due to the limited seepage of groundwater into the watercourses.

Stream quality is influenced by a range of human activities. The principal are discharges of wastewater from households and industry, and cultivation of the open land in the form of agriculture, horticulture, and forestry. Rough management of watercourses will also have a large influence on their quality. Good stream quality, with diverse animal- and plant-life, has three prerequisites: the water should be clean, there should be sufficient water, and the physical conditions in and around the stream should be favourable.

Good stream quality has 3 elements



Good water quality **is characterised by low levels or the absence of:**

- **oxygen-consuming substances**
- **nutrients**
- **disease-causing organisms**
- **toxic, hazardous substances**

Good physical conditions **are characterised by:**

- **large variation in stream bottom substrates (sand, gravel, stones, etc.)**
- **variable current conditions, and without artificial dams or barriers. Such conditions characterise a natural, unregulated stream which is allowed to meander freely**

Environmental conditions in streams

Surveillance of the environmental quality in the watercourses in Fyn County began in earnest after passing of the Environmental Protection Act in 1973. Results from earlier surveys are, however, available for some watercourses, and in many cases can help our understanding of developments in environmental quality in general.

Invertebrates as environmental indicators

Faunal composition is dependent on, among other things, the size of the watercourse and its flow, substrate conditions, and the amounts of oxygen-consuming substances (BOD_5) and toxic chemicals (see below). Invertebrates are, thus, well suited as biological indicators of environmental quality.

More than 300 different species of invertebrates are present in the County's watercourses, though only a few are widespread and abundant. Most numerous is the amphipod *Gammarus pulex*, which constitutes some 25% of the total fauna.

Marked improvements in larger streams

During the period 1976-1999 there have been marked improvements in water quality in the larger streams in Fyn County, when the parameters BOD_5, phosphorus, and ammonium-nitrogen are considered. Annual mean concentrations of these substances have been reduced by a factor of two to five during the period 1976-1999 (Figure 6.3).

Biological conditions - assessed by the Danish Stream Fauna Index (Skriver et al., 2001) - have improved significantly in the last 10 to 15 years (Figure 6.1). This is most evident in larger streams, the proportion of which with acceptable conditions having doubled from 30 to 60%. Particularly evident is the increase in the proportion of the cleanest streams (Faunal Class 5-7), and the decrease in the proportion of the most polluted ones (Faunal Class 1-3).

The reason for these environmental improvements is, in particular, the effective treatment of municipal wastewater. Also important is cessation of previously common illegal agricultural discharges of liquid manure and silage juices. The introduction of more environmentally friendly watercourse management practices has also improved the "self-cleansing" capacity of the streams.

Poor environmental conditions in small streams

Improvements comparable to those seen in large streams have not, however, occurred in smaller streams, where only some 20% have an accep-

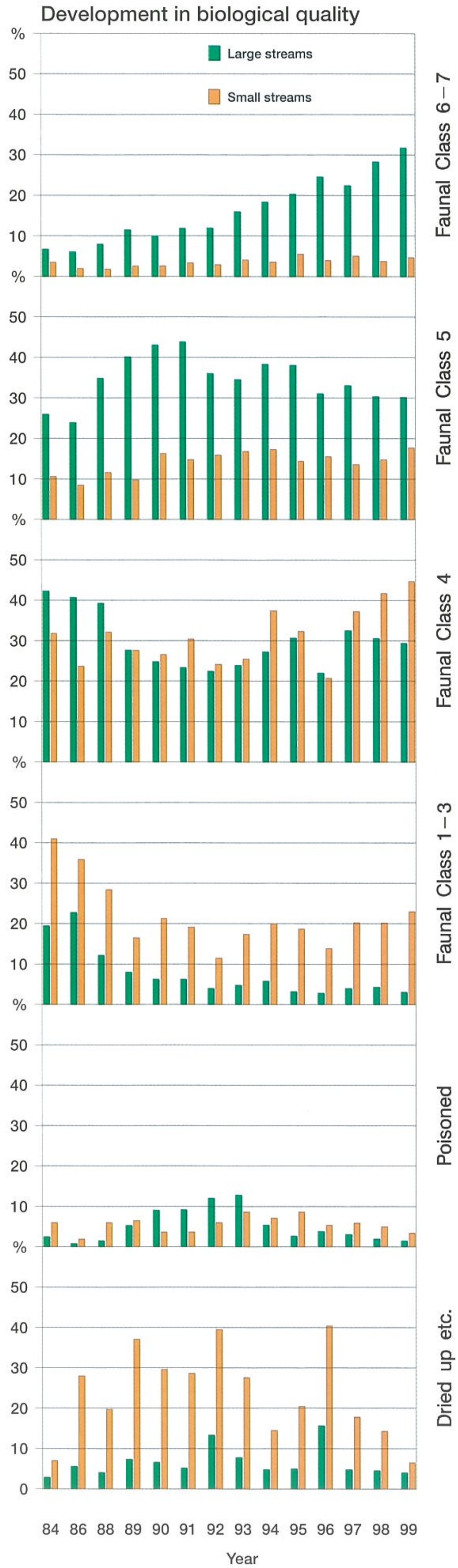


Figure 6.1
Trends in biological quality of watercourses in Fyn County during the period 1984-1999, based on data for approx. 900 sites equivalent to 1340 km of watercourses. Data are presented for large and small watercourses separately.

Biological quality is based on an assessment of macroinvertebrate assemblages, and measured by the Danish Stream Fauna Index (Skriver et al., 2001) on a scale of 1 to 7, with the faunal classes having the following explanation:

- *6-7 essentially unimpacted*
- *5 slightly impacted*
- *4 moderately impacted*
- *1-3 highly impacted*

In addition, 'poisoned' means that certain key invertebrates have been eliminated by e.g. pesticides, and 'dried up' indicate that stream bottom was totally or almost dry.

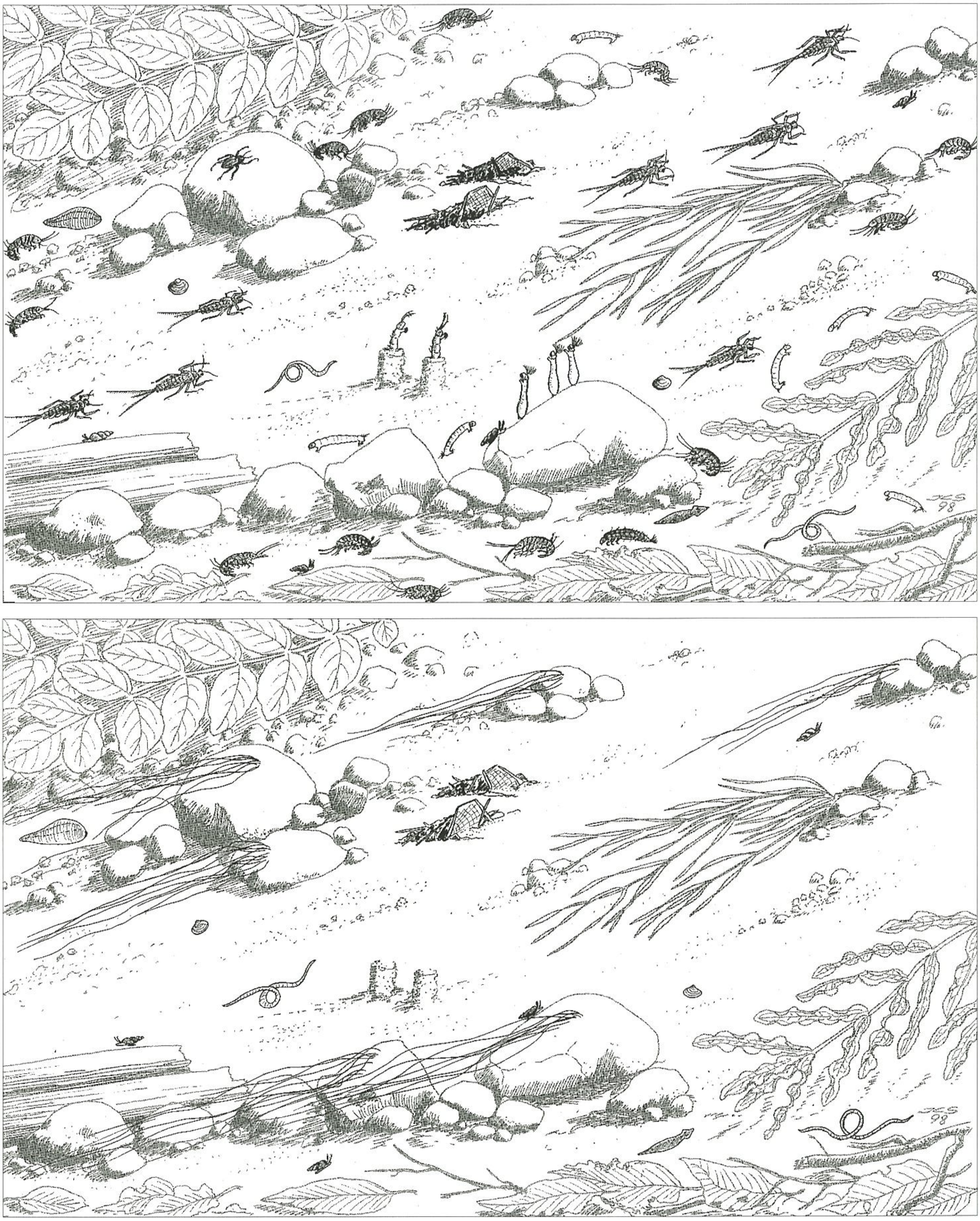


Figure 6.2
Upper panel: *Macroinvertebrates in a typical, unregulated stream in Fyn County with good water quality. Note the numerous* Gammarus *and different insects.*
Lower panel: *A pesticide discharge has eliminated all* Gammarus *and insects, leaving only worms, snails, and mussels. (Drawing by Jens Christian Schou).*

Water quality of 19 streams in Fyn County 1976-1999

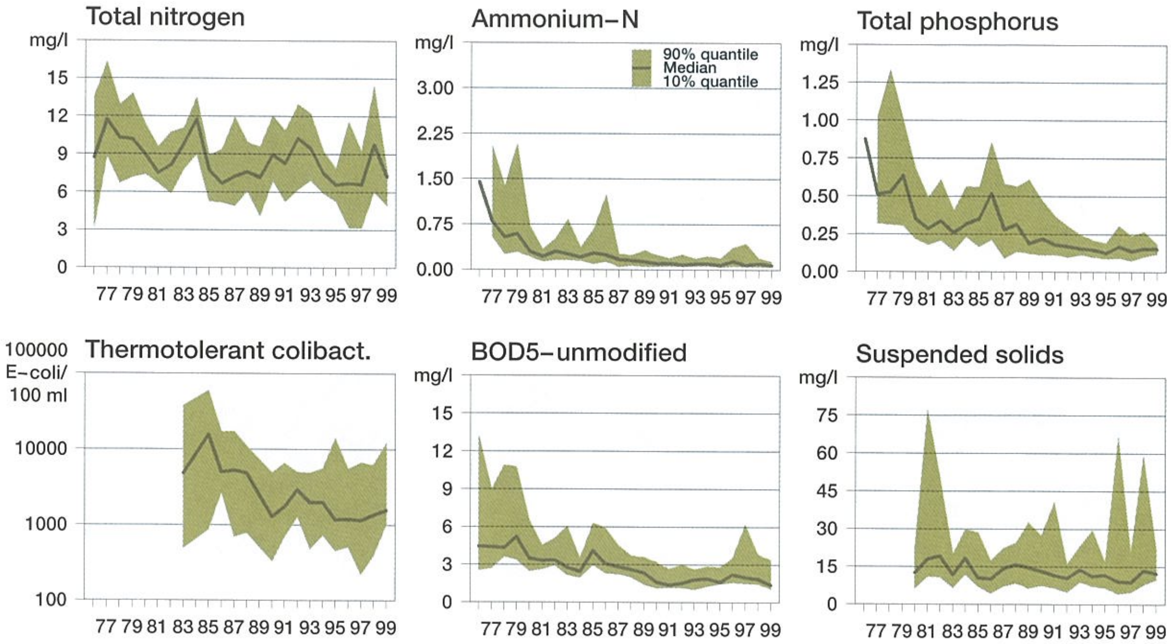


Figure 6.3
Developments in water quality in 19 large streams (combined) in Fyn County during the period 1976-1999. The annual mean concentration for each water quality variable is shown for each year. Each value represents a minimum of 228 analyses.

table quality. The primary reason is poorly treated wastewater discharged from scattered homes and rural villages, which results in, among other things, high levels of oxygen-consuming substances in the watercourses (Table 6.1). Also playing a role is the fact that small streams generally have less-favourable physical characteristics, partly as a result of rough management practices and former stream regulations.

Excessive levels of nutrients and pathogenic bacteria

Compared to 'natural' streams, the majority of watercourses in Fyn County continue to have greatly elevated concentrations of nitrogen and phosphorus. The levels of nutrients are typically so high as to prevent the lakes and fjords into which they flow from meeting their quality objectives. A description of the transport of nutrients in watercourses, including the origins of nutrients and temporal changes in nutrient loads, is presented in Chapter 5.

To date, a largely unaddressed problem is the hygienic quality of the water which, in the majority of watercourses, is unacceptable, although there has recently been a significant decrease in bacterial number in the larger streams (Figure 6.3). Discharge of wastewater has resulted in watercourses having high levels of pathogenic bacteria and viruses. This can increase the risk of disease for people or animals which come in contact with the watercourses or water from them.

Drying-up in summer - an environmental problem

A proportion of the streams in Fyn County regularly dry up during the summer months. This was especially evident 1996, when 25% of watercourses dried-up as a result of record-low precipitation the previous year. Small watercourses were most severely affected, with one-in-three drying up. This had not only had an immediate effect on the invertebrate communities and fish populations, as the watercourses that dried up appeared more polluted the following year. Thus, less-pollution tolerant species had difficulty re-colonising the watercourses.

Relationship between water quality and faunal class

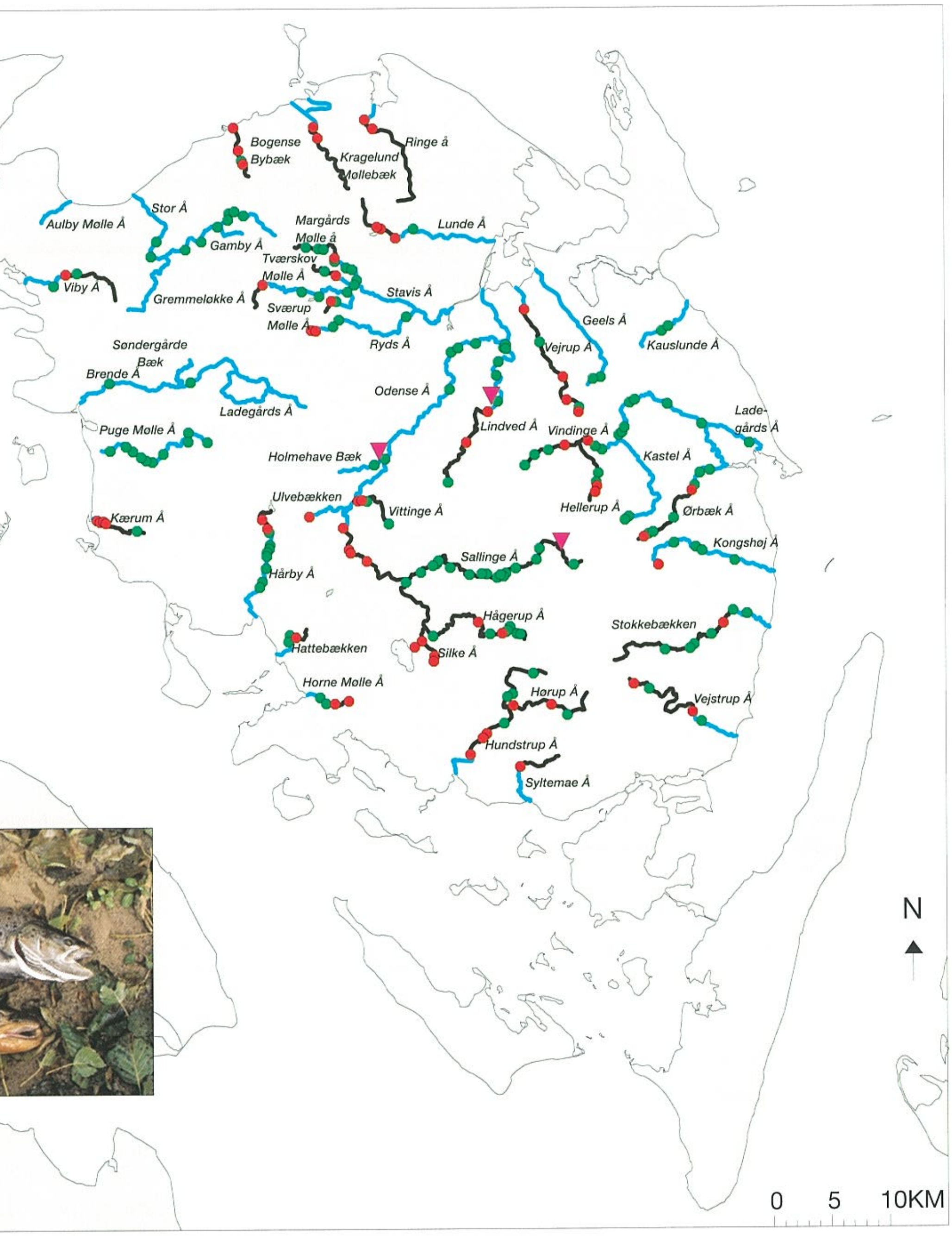
Compound	Quality objective met (Faunal class 5-7)			Quality objective not met (Faunal class 1-4)		
	Max	Mean	Min	Max	Mean	Min
BOD_5 (mg/l)	2.94	1.57	0.65	21	3.20	0.50
Ammonia-N (mg/l)	0.25	0.14	0.036	13	0.37	0.013

Table 6.1
Levels of oxygen-consuming substances (BOD_5 and ammonium-nitrogen) in two groups of small streams in Fyn County, namely those (11 streams) in which biological quality objectives have been met, and those (50 streams) in which objectives have not been met.

Figure 6.4
Locations of obstructions, registered by Fyn County Council, that prevent the passage of migrating fish in larger streams in Fyn County. Also shown are locations at which Fyn County Council and other organisations have completed stream restoration projects that have provided free passage for migrating fish.

Legend:

- New river bed under construction
- Obstruction for fish
- Passage established/ obstruction removed
- Free passage for fish
- Not accessible to fish



Sea trout caught by electrofishing during a survey of the ascent of sea trout in streams in Fyn County.

Photo: Niels B. Adamsen, Fyn County Council

The fish ladder built in Brende Å by the 'Brende Mølle Foundation'.

Photo: Claes Levin Pedersen, Fyn County Council

Abstraction of groundwater for, among other uses, drinking water and irrigation influences discharge in the watercourses, especially during the summer. Thus, increased abstraction may make the watercourses dry up more frequently. As a result, the Regional Plan for Fyn County has established guidelines with the aim of ensuring, among others things, that environmental interests are taken into consideration when permits to abstraction of water is given.

Assisting migrating fish

From the 1200s onwards, watercourses have been dammed at many locations to provide water for watermills or water-meadows. This, together with the piping of sections of streams, has prevented sea trout (*Salmo trutta*) from reaching suitable spawning grounds in the upper reaches of the stream systems. During the last 10 years, Fyn County Council, in collaboration with the Danish State, municipalities, and private landowners, has established free passage for such fish at some 70% of the 219 known obstructions in County-managed streams (Figure 6.4). In particular, smaller obstructions have been removed, though free passages have also been created around many larger mills. As the trout populations are highly dependent on recruitment from sea trout, the necessity of releasing captive-bred fish has been reduced. Fyn County Council has initiated a major 'Sea Trout Project' that has been a decisive factor in achieving these results. Since 1999, the County Council has spent approximately 1.5 million Danish kroner a year on fish passages.

Photo: Annette Sode, Fyn County Council

Fresh, green growth of the filamentous alga Cladophora *on the bed of a stream.*

25 cm

Photo: Annette Sode, Fyn County Council

At high magnification the alga is clearly seen to be branching.

0,25 mm

Filamentous algae - an environmental problem?

Cladophora is the dominant filamentous alga in watercourses in Fyn County. Mats of these algae, which may have deleterious effects on other stream organisms are, however, relatively rare. Thus in 1996, only 10% of the total length of watercourses had filamentous algae covering more than one fifth of the stream bottom.

Whereas the in-stream concentrations of nitrogen and phosphorus do not seem to have a direct influence on the well-being of invertebrates and fish, algal growth is dependent on the level of these nutrients. Surveys by Fyn County Council show that blooms of filamentous algae only occur if the concentration of dissolved phosphorus exceeds 0.02 - 0.03 mg P/l. Phosphorus concentrations are, however, in general considerably higher than this value.

Development of filamentous algal blooms is thus dependent on several other factors, the most important being light intensity, substrate characteristics, and local water current conditions (Figure 6.5). In addition, grazing invertebrates appear to be able to control algal biomass. As a result, rapid growth of filamentous algae occurs if the populations of grazers (e.g. *Gammarus* and certain aquatic insects) are heavily reduced due to inputs of pesticides.

Increasing densities of trout in County-managed streams

Wastewater treatment, not unexpectedly, has had a considerable positive effect on the well-being of fish in watercourses. However, surveys have to date shown that the transition to environmentally friendly watercourse management is responsible for an at least fourfold increase in trout densities in County Council managed watercourses. The improvement is primarily attributed to a greater abundance of shelter for fish.

What determines the occurrence of filamentous algae?

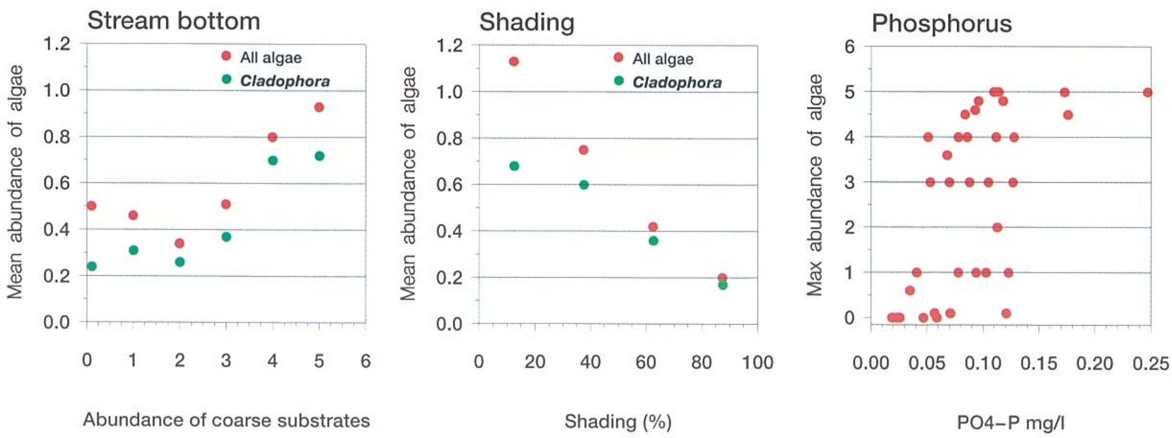


Figure 6.5
Occurrence of filamentous algae in streams in Fyn County as a function of certain important factors, namely substrate characteristics, degree of shade (from trees etc.), and concentration of dissolved phosphorus.

Hazardous substances

In recent years, Fyn County Council has surveyed selected streams for the presence of a broad range of hazardous substances, including pesticides. The following section discusses the pesticide results of these surveys, whereas results regarding the other compounds are mentioned in the section on wastewater in Chapter 5.

Pesticides affect the stream biota

The invertebrate surveys conducted by Fyn County Council at the beginning of the 1990s showed a disturbing increase in the extent of watercourses acutely affected by toxic discharges (Figure 6.1), most likely of pesticides. These toxic discharges represent a serious environmental problem, as they not only affect certain species, but also the biological structure of the streams. As previously stated, toxic discharges have resulted in unattractive blooms of filamentous algae in watercourses. These, in turn, give poorer conditions for invertebrates and the trout that feed on them. During the period 1988-99, more than 200 km of stream reaches have experienced acute damage, resulting in a heavily decrease in the populations of crustaceans and aquatic insects.

This has reduced the environmental benefits gained from the considerable investments in wastewater treatment (approximately 2 000 million Danish kroner alone in Fyn County) during recent decades. Without the serious effects of pesticides, approx. 10% more of the large watercourses would have had an acceptable biological quality.

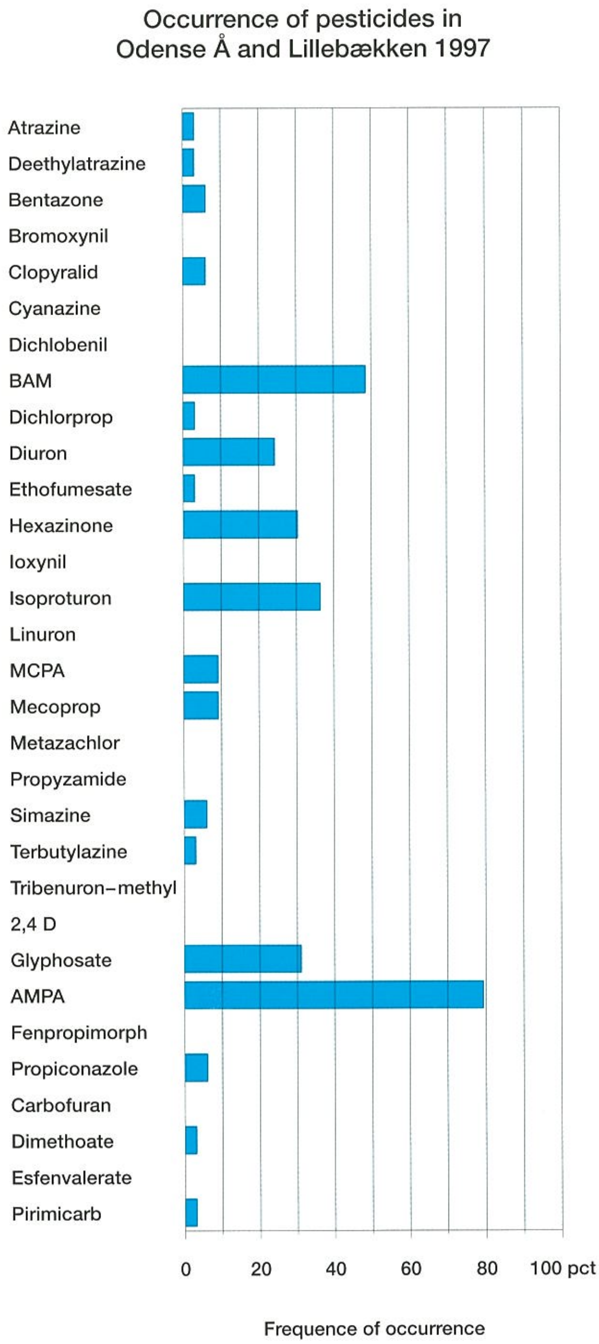


Figure 6.6
Frequency of pesticides and selected breakdown products of these compunds (BAM = 2,6-dichlorobenzamide; AMPA = aminomethylphosphoine acid) in Odense Å and Lillebækken in 1997. Only pesticides present at concentrations ≥0.1 µg/l are shown. Values are based on analyses of 33 water samples. See Appendix 2A for more detailed data for the whole period 1994-98.

> **Types of streams surveyed for the presence of pesticides**
>
> - **streams in catchments with mixed land use and including towns and villages**
> - **streams draining forested areas only**
> - **streams draining agricultural land with scattered homes**

Pesticide surveys

Fyn County Council has completed a survey of pesticides in selected streams (including drains) that represent catchments with three different types of land use. During the period 1994-98, a total of 262 water samples were taken in these streams. Each sample was typically analysed for 97 different pesticides, with a total of 99 pesticides analysed for during the five-year period. Thirty-nine different substances were found in concentrations up to 11 µg/l. They included 31 herbicides, 2 fungicides, and 6 insecticides. Most substances were present at concentrations of more than 0.1 µg/l (Appendix 2A). In the same sample, up to 18 different pesticides were present in a single watercourse (Table 6.2). Of the 39 substances detected, 29 are permitted today. One substance - metazachlor - has never been permitted in Denmark (Appendix 2A) and its presence therefore most likely reflects illegal import and use.

Glyphosate, which is considered one of the most 'environmentally friendly pesticides', in part because of its allegedly small potential to be washed out from the soil, was also among substances detected. It was present in streams at con-

Pesticide records 1994-1998	Number of compounds	Max. conc. of single compounds µg/l	Max. conc. of all compounds µg/l	Max. number of compounds present concurrently
Odense Å (mixed use catchment)	32	1.0	3.1	18
Lillebæk (agricultural catchment)	33	10.0	12.1	18
Forest stream	5	2.0	2.1	2
All streams	39	10.0	12.1	14
Field drains	16	11.0	11.7	6
Mixed function drains	16	3.0	7.7	14
All drains	21	11.0	11.7	14

Table 6.2
The occurrence of pesticides in streams and drains in Fyn County. Drains are divided into those that drain solely agricultural land (field drains) and those that, in addition to draining fields, also drain farmyards, and receive wastewater from scattered homes (mixed function drains). See also Appendix 2A og B.

centrations of up to 2.7 µg/l, whereas concentrations up to 11 µg/l were found in drains adjacent to fields. Please consult Appendix 2A and B for a complete overview of the pesticides detected in streams and drains.

Isoproturon and glyphosate - the most frequently found pesticides

Considering only the survey in 1997 and concentrations above 0.1 µg/l (Figure 6.6), AMPA (aminomethylphosphoine acid) was the most frequently recorded substance, being found in 79% of the samples, followed by BAM (2,6-dichlorobenzamide) (48%), isoproturon (36%), glyphosate (31%), hexazinone (30%), and diuron (24%). AMPA and BAM are degradation products of glyphosate and dichlobenil, respectively. Glyphosate and isoproturon, both permitted for use in 1997, have been among the most commonly used pesticides in Denmark, although isoproturon was prohibited as of 1 December 1999, and the use of glyphosate is now being reconsidered by the Danish Environmental Protection Agency.

Pesticide prevalence and local use

Pesticides have been found in all three types of streams, but the highest number of compounds was recorded in Lillebækken, which only drains agricultural land, and in Odense Å, which drains a catchment containing all potential users of pesticides (farming, horticulture, public institutions, and private households). Only a few pesticides were present in streams draining forested catchments (Table 6.2).

In the catchment of Lillebækken, interviews with farmers confirmed that most of the substances detected were actually used. Similarly, pesticides present in forest streams were those typically used in forestry practices. This indicates, that the substances found originated from sources in the respective catchment, and therefore do not appear to be due to atmospheric- or precipitation-associated deposition related to activities outside the catchments.

Residues of DDT in stream sediments

A survey in autumn 1997 of bottom sediments in Lillebækken and Odense Å revealed 4 and 5 of a total of 22 analysed pesticides, respectively. The substances found were four insecticides and one fungicide. Only one substance, esfenvalerate, was also found in the water column.

The sediments examined were the loose, surface fractions which, in strong water currents, are transported downstream to lakes or coastal waters. Such sediments are deposited in the stream bottom when discharge and current are low (typically from late spring to early autumn), and are resuspended when water flow rises in the autumn.

Although DDT - an extremely environmentally harmful pesticide - was prohibited in Denmark in 1984, its degradation product DDE was still present in both the river Lillebækken and river Odense Å approx. 13 years later (see box below). In addition Vinclozolin was found. This substance is on the Danish "A-List", meaning that it cannot be used as a pesticide after 31 December 1997. The remaining three substances (including esfenvalerate) are currently permitted pesticides in Denmark.

Pesticides detected in stream sediments

Substance	Maximum concentration (µg/g dry weight)
Alpha-Cypermethrin	0.003
DDE	0.02
Esfenvalerate	0.003
Permethrin	0.03
Vinclozolin	0.002

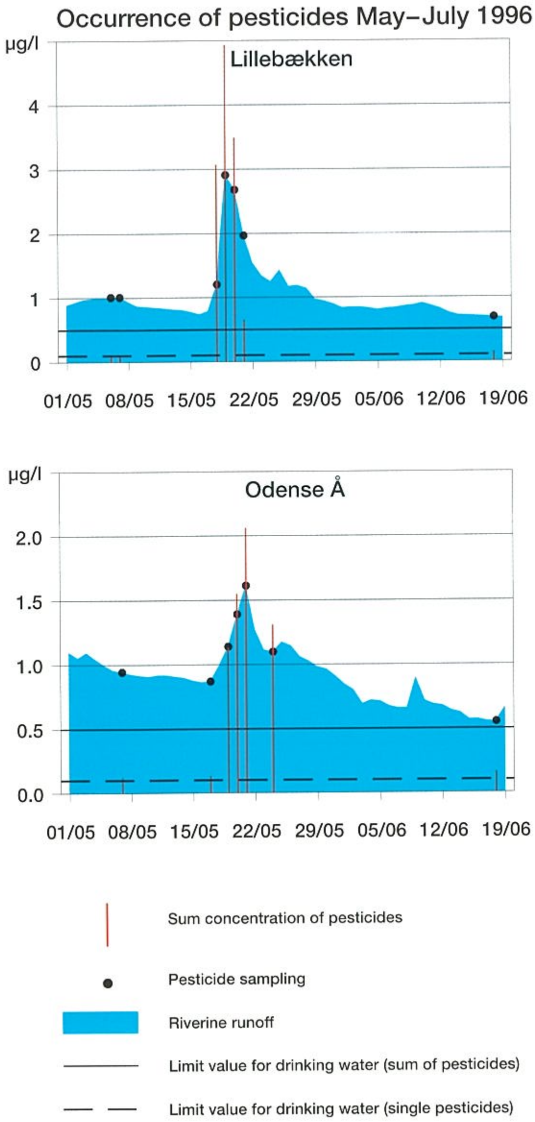


Figure 6.7
Total pesticide concentrations (red columns) in Odense Å and Lillebækken associated with heavy rainfall in May 1996. Note that concentration of pesticides increased markedly as discharge (blue area) increased due to the heavy rain. In all, 13 different pesticides were detected in each of the two rivers.

Pesticides most frequent in streams during the spraying season and after rain

The greatest number and highest concentrations of pesticides are found in the spraying season (April to November) following precipitation that causes an increase in water flow in watercourses (Figure 6.7). In the years 1994-1996 survey during the spraying season showed that pesticide levels in Odense Å and Lillebækken after rain were 6-times and 19-times, respectively, those in the streams during dry weather. Further, 12 different substances were detected in dry weather, whereas in periods following rain 30 different substances were detected.

Pesticides in drains

In December 1996, the presence of pesticides was investigated concurrently in Lillebækken and four field drains discharging into this small stream. Three of five substances detected in the stream were also detected in the drains.

The investigation was repeated during one day in October 1997, revealing 18 different pesticides in Lillebækken and 19 pesticides in the 11 field drains. Fourteen of these were present in both stream and field drains, and 9 substances were detected in 4 drains only draining agricultural land. The remaining 5 substances detected were present in drains that are also believed to receive wastewater from scattered homes, runoff from farmyards etc. (see Appendix 2B).

These surveys confirm that it is most likely that a major part of the pesticides present in streams enters via field drains, particularly during the spraying season. Thus, wind drift is not considered to be a significant factor influencing the presence of pesticides in the streams examined.

Pesticides in wastewater

A pilot study in June 1997 of pesticides in wastewater discharged by Ejby Mølle treatment facility revealed 11 substances at concentrations of up to 2.0 µg/l (see Appendix 2B). The study comprised two inlet and two outlet samples that were analysed for 85 different pesticides. Six and 11 pesticides, respectively, were detected in wastewater entering and leaving the facility, with three substances being present in both the influent and effluent. In adition, two samples of sewage sludge from the facility were taken concurrently with the water samples. They were analysed for 21 pesticides, with two substances being detected (see box below).

Thus, the addition of pesticides to surface waters also occurs via wastewater treatment plants, which receive wastewater from both households and industry, and rainfall collected in built-up areas. The investigation was, however, not of sufficient scope to draw any general conclusions on the presence of pesticides in wastewater.

Pesticides detected in wastewater sludge

Substance	Maximum concentration (µg/g dry weight)
Cypermethrin	0.3
Permethrin	0.1

Compound	Max. conc. in stream (µg/l)	Harmful concentration (µg/l)	Effects	Reference
Isoproturon	1.0	5	Reduced abundance of diatoms	Pérès et al. (1996)
Propiconazole	0.8	0.3-0.8	Reduced algal growth	Källqvist & Romstad (1994)
		1-10	Change in algal composition	-
Dimethoate	0.7	1	Increased drift/ reduced density of invertebrates	Bækken & Aanes (1994)
		7	Acutely toxic to the mayfly *Baetis rhodani*	-
Pirimicarb	3.0	10-18 (<1)[1]	Acutely toxic to *Daphnia magna*	Kusk (1996)
Esfenvalerate	0.2	0.08-0.2	Reduced density of copepods	Lozano et al. (1992)
		0.25	Reduced density of zooplankton / other invertebrates	Fairbrother et al. (1991)

Table 6.3
Minimum concentrations of selected pesticides that have documented adverse effects on aquatic organisms. Also shown are the highest concentrations of these pesticides measured in streams in Fyn County during the period 1994-1997.
[1]) According to Kusk (1996) primicarb is 10-40 times more toxic than dimethoate to Daphnia magna. *This means that acute damage to certain stream invertebrates can be expected at concentrations <1 µg/l.*

Pesticides in springs

Surveys in 1994 and 1995 detected two pesticides, and traces of a third, in two of four springs that are included in the Danish Aquatic Monitoring and Assessment Programme (see box to the right). Pesticide concentrations of up to 3 µg/l were found, which is some 30-times the maximum permitted level for drinking water. Spring water was analysed for the presence of a total of 88 different pesticides.

Pesticides detected in springbrooks

Substance	Maximum concentration (µg/l)
Desethylatrazine	trace (< 0.1)
2,6-dichlorobenzamide (BAM)	0.5
Hexazinone	3.0

Insufficient knowledge of the environmental effects of pesticides

Little is known about the effects pesticides have or may have on aquatic animals and plants in Danish streams. Most foreign studies have considered 'exotic' species, and there is almost no information on effects resulting from the simultaneous presence of a number of pesticides.

Some of the pesticides detected, however, have been present at concentrations known to be harmful to both plants and animals (Table 6.3). These effects include acute toxicity as well as sublethal effects, e.g. expressed as animals being unable to complete their development from egg to adult, or adult animals being unable to reproduce.

Examination of watercourses may provide important indications of effects of pesticides on the entire aquatic environment, as the results reflect the aggregate effects of pesticides over large areas.

Photo: Karin Villebro, Fyn County Council

St Oluf's Well at Trente Mølle (Broby Municipality). The pesticide residue, BAM (2,6-dichlorobenzamide), was found in water samples taken here.

The probable effects of pesticides on watercourses are disturbing, partly because the full consequences for the environment are not known.

There are many attractive lakes in Fyn County, such as Dallund Sø near the town of Søndersø. *Photo: Jan Kofoed Winter*

7 Lakes

There are approx. 8 900 lakes and ponds with a surface area of more than 100 m^2 in Fyn County. They cover a total surface area of 28 km^2, equivalent to 0.8 % of the County's area. Both the number and total area of lakes on Fyn is a little under the average for Denmark. Relatively large lakes are few, and the four largest - Arreskov (317 ha), Brændegård (108 ha), Nørresø (69 ha), and Hvidkilde (61 ha) - are all located in southern Fyn (Figure 7.6). Many small lakes are present in the gently-undulating moraine landscape that covers much of the County, particularly in the hilly countryside around the town of Vissenbjerg (central Fyn). The low plains of northern Fyn have few large or small lakes, partly because many low-lying areas have been drained.

The lakes are generally shallow, typically less than 5 m deep. Thus, the deepest natural lakes - Søholm Sø and Nordby Sø - have maximum depths of only 15 m and 9 m, respectively.

The landscape of Fyn is mainly composed of clayey moraine earth deposited during the last ice age, so that the majority of lakes are naturally rich in nutrients and chalk. Sortesø in southern Fyn is an example of a naturally nutrient-poor, humic lake, that has developed in a sandy area.

In addition to natural lakes, many man-made lakes and ponds have arisen over the years as a result of digging for marl and peat, damming of streams to supply water for water mills, and, in recent decades, quarrying for gravel and the establishment of duck game ponds. However, many lakes and ponds have disappeared over the last 100 years. For example, the number of lakes in the catchment of Arreskov Sø has decreased from 276 in 1890 to 65 in 1992, a reduction of 76 %.

Thirty-four of the County's largest lakes are included in the Regional Plan, which sets objectives for their quality and use (Figure 7.6). The environmental quality of these lakes has been investigated to varying degree since 1972. The following discussion of the condition and development in these lakes is based on the results of these investigations.

Monitoring of hazardous substances has, to date, only been carried out in two lakes (Arreskov Sø and Nørresø). Three substances were found, though only in low concentrations. Fur-

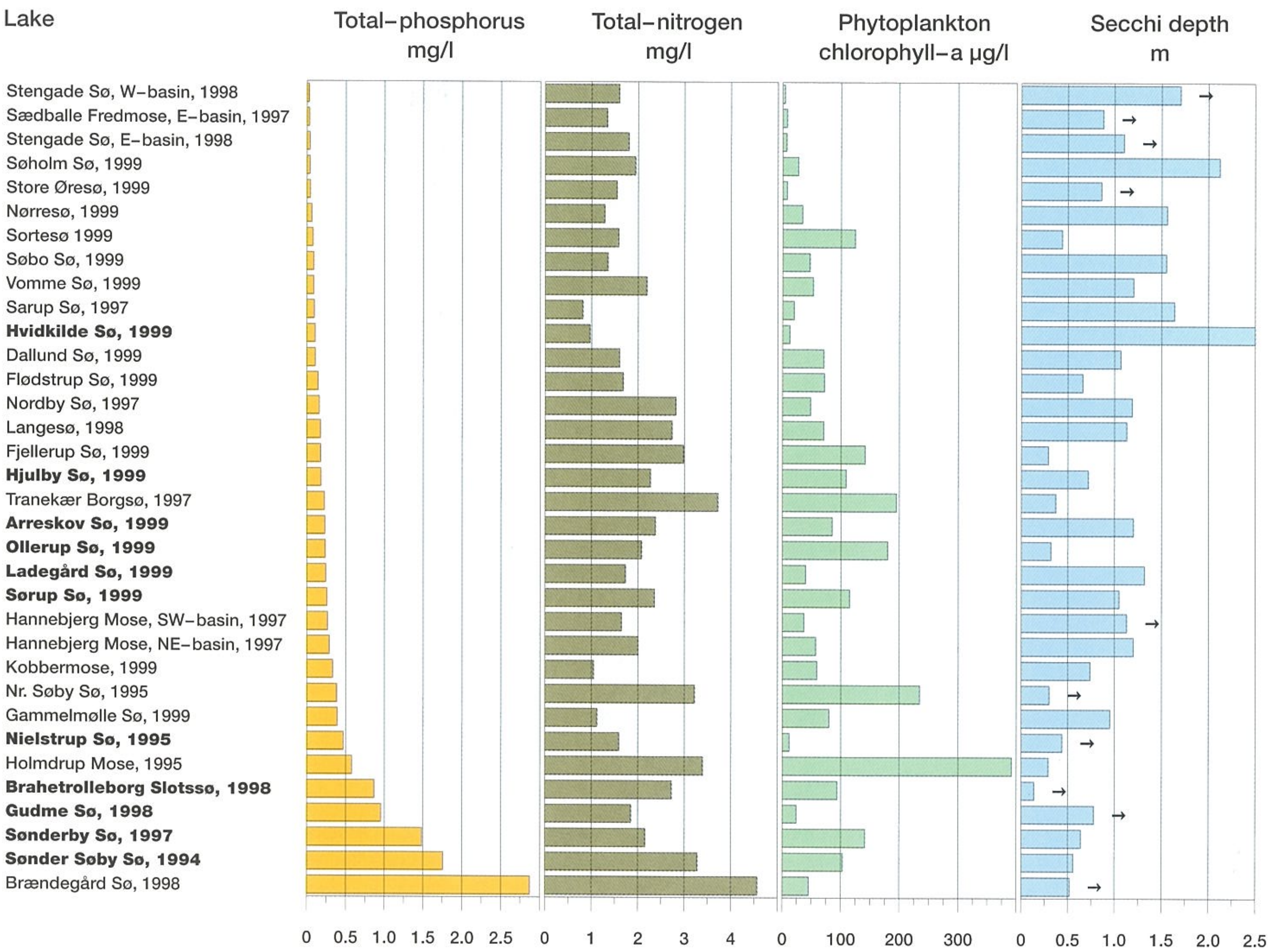


Figure 7.1
Concentrations of phosphorus and nitrogen, algal abundance, and secchi depth in 34 lakes. Values are mean for the summer period 1 May -30 September. The year for which the data pertain is shown after each lake. An arrow after a secchi depth value indicates that, on many occasions, secchi depth extended to the bed of the lake and so the true value was higher. Lakes that have previously received wastewater from municipal treatment plants are shown in bold.

ther investigation of the distribution and concentrations of these substances in Arreskov Sø will be made as part of the NOVA 2003 programme (see Chapter 3).

Current conditions

Concentrations of the nutrients phosphorus and nitrogen are high in most of the lakes in the County. These substances act as a fertiliser for algae, allowing them to grow rapidly and turn the water green and cloudy.

Natural levels of total phosphorus in the majority of lakes in Fyn would be less than 0.05 mg/l. The concentrations actually found in most lakes are, however, much higher (Figure 7.1), especially in those lakes which have previously received municipal wastewater (shown in bold in Figure 7.1). The fact that these lakes no longer receive wastewater does not necessarily mean a rapid improvement in conditions. This is partly due to the release of nutrients that have accumulated in the sediments, and partly because remaining inputs of nutrients to the lakes may still be excessive. Direct discharges of wastewater from scattered houses, and runoff of phosphorus from agricultural land, will together increase the amount of phosphorus in lakes.

Most lakes also contain high levels of nitrogen (Figure 7.1), especially those located in intensive farming areas. Nitrogen washed from fields enters these lakes via ditches and streams.

Due to the high nutrient levels, the abundance of planktonic algae is high and transparency low (Figure 7.1). In roughly half the lakes secchi depth is less than 1 m, whereas it should typically be more than 3 m in clear-water lakes. Low transparency has caused submerged plants to disappear, reducing the habitats of fish and benthic invertebrates, which lead to an overall impoverishment of fauna and flora. Only 4 of the 34 lakes investigated have what can be considered a natural and balanced flora and fauna, and thus meet the objectives set out in the Regional Plan (Figure 7.6).

Developments since the 1970s

Some 22 lakes in Fyn have been studied for a sufficiently long period (15-25 years) that changes in their condition can be reliably assessed. Table 7.1 shows the extent of changes in average concentrations of nitrogen and phosphorus, algal abundance (measured as chlorophyll-a), and secchi depth in these lakes. The table shows that measures to control pollution of the lakes have had limited success, though there have been a few positive developments (highlighted in green).

Lakes previously receiving wastewater

Since 1972, the discharge of municipal wastewater to a number of lakes has been stopped or reduced. The most significant measures were introduced in the 1980s, with the result that wastewater discharges to nine lakes were stopped. There can, however, still be stormwater discharges. Only two lakes, Hjulby Sø and Ladegård Sø, still receive wastewater from municipal treatment plants, though the wastewater has first undergone effective treatment.

In lakes to which the discharge of urban wastewater has been reduced significantly or stopped, phosphorus concentrations have generally decreased. In one lake (Gudme Sø), however, phosphorus concentrations have risen due to an increase in the release of phosphorus from the sediments. In other lakes (Arreskov Sø and Hvidkilde Sø) phosphorus levels have declined in recent years, though the decrease is not statistically significant over the whole survey period (1974-1998). Nitrogen concentrations have likewise decreased in several lakes.

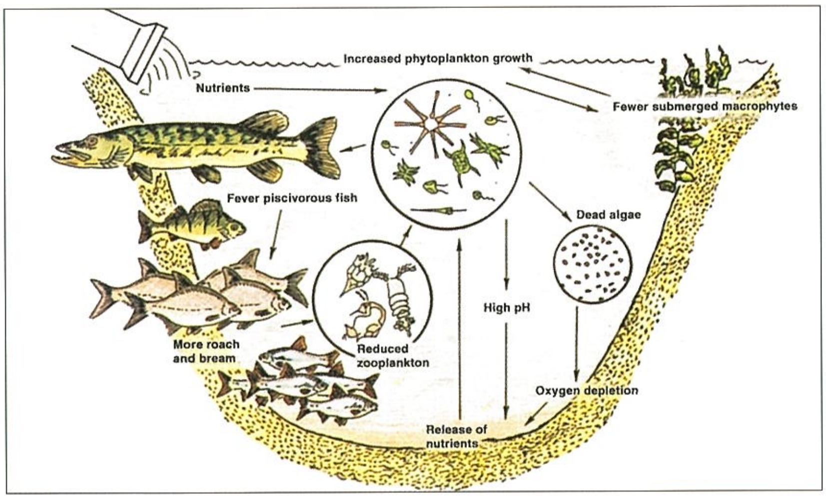
In several lakes the decrease in phosphorus and/or nitrogen concentrations is associated with a decline in the abundance of planktonic algae and/or a limited increased secchi depth. Biological conditions are expected to be significantly improved if secchi depth has increased to such an extent that submerged plants are able to successfully recolonise the lakes. To date this has only occurred in Arreskov Sø, and even here the area colonised by submerged vegetation varies considerably from year-to-year.

Bloom of blue-green algae in Hjulby Sø. Such blooms occur each summer in many lakes in Fyn County due to their high nutrient concentrations.

Photo: Kjeld Sandby Hansen, Fyn County Council

Lakes in catchments dominated by agriculture and scattered houses

The majority of lakes in catchments dominated by agriculture and scattered houses are still polluted as a result of the input of excessive nitrogen and phosphorus. Thus, only one lake (Sarup Sø) in this category fully meets its water quality objective. Phosphorus concentration and algal abundance have decreased in Søholm Sø, partly



Pollution of lakes

The addition of excess nutrients, particularly nitrogen and phosphorus, to a lake acts like a fertiliser for planktonic algae, which grow rapidly and turn the water green and cloudy. Algae prevent light reaching the lake bottom, and with insufficient light submerged plants disappear. When the algae die, they sink to the bottom where they rot. This results in oxygen depletion in the bottom waters, which is harmful to invertebrates and fish. Poor oxygen conditions also result in the release, into the overlying water, of nutrients that have accumulated in the lake sediments. This can fuel renewed algal growth. Fish such as roach (*Rutilus rutilus*) and bream (*Abramis brama*) thrive in the murky water, partly because pike (*Esox lucius*), their main predator, have difficulty in finding them. Roach and bream eat large zooplankton such as daphnids which, in turn, eat phytoplankton. Fewer daphnids result in more algae, leading to a cycle of deteriorating environmental quality.

	Lake	Period	Nitrogen	Phosphorus	Chlorophyll-a	Secchi depth
Lakes previously receiving town wastewater	Arreskov Sø	1974-99	↓	(↓)	(↓)	↑
	Gudme Sø	1981-98	0	↑	↓	*
	Hjulby Sø	1974-99	0	↓	↓	0
	Hvidkilde Sø	1974-99	↓	(↓)	↓	↑
	Ladegård Sø	1974-99	0	↓	↓	↑
	Ollerup Sø	1974-98	↓	↓	0	0
	Sønderby Sø	1980-97	0	↓	0	0
	Sørup Sø	1974-99	↓	↓	0	0
Catchments with agriculture and scattered homes	Dallund Sø	1981-99	0	(↓)	↓	↑
	Fjellerup Sø	1983-99	0	0	0	0
	Flødstrup Sø	1983-99	*	*	0	0
	Gammelmølle Sø	1985-97	*	*	0	0
	Kobbermose	1985-99	*	*	0	0
	Langesø	1981-98	0	0	↓	↑
	Nordby Sø	1981-97	0	0	↓	↑
	Sarup Sø	1983-97	(↓)	0	↓	↑
	Søbo Sø	1983-99	↓	↓	↓	↑
	Søholm Sø	1980-99	0	↓	0	0
	Vomme Sø	1980-99	↓	0	↓	0
'Natural' (inc. forested catchments)	Nørresø	1974-99	0	↓	0	0
	Sortesø	1985-98	↑	↑	↑	↓
Catchments with special characteristics	Brændegård Sø	1974-98	0	↑	0	*

*Table 7.1 Developments in the concentrations of nitrogen and phosphorus, algal abundance, and secchi depth in 22 lakes in Fyn. Note that data cover different periods in the various lakes. Arrows (↓/↑) indicate a statistically significant (P<0.05) increase or decrease based on linear regression of log-transformed mean summer values. Parentheses indicate an increase or decrease that was not statistically significant. '0' indicates that there was no change. * indicates that there were too few measurements to assess trends or, in the case of secchi depth, that this extended to the lake bottom and, thus, does not accurately reflect the true value.*

Importance of submerged plants

Submerged plants are important for life in lakes, and help keep the water clear as:

- **they stabilise the bottom sediments preventing resuspension**
- **they take up nutrients, especially nitrogen, from the water and sediment so that the nutrients are not available for algal growth**
- **zooplankton (e.g. daphnids) can shelter amongst vegetation and so escape predation by fish**
- **they improve conditions for the lake's predatory fish, offering shelter for juvenile perch and pike, and being the preferred habitat of adult pike**
- **they are an important habitat of many invertebrates, thereby increasing biodiversity, and the important food for certain waterfowls**

due to the cessation of illegal discharges of slurry etc., while in Søbo Sø and Dallund Sø this is partly the result of biomanipulation (see below). Thus, although individual lakes have shown reduced concentrations of nitrogen and/or phosphorus, no general trends for reduced levels of nitrogen and phosphorus and improvements in algal growth and secchi depth have been observed.

Lakes in 'natural' or forested catchments

Only a few lakes are situated in forested catchments or catchments that can be considered natural. Sortesø, a clean, humic lake, meets its water quality objectives, though since the mid-1980s nutrient concentrations and algal abundance have increased. This is attributed to increasing atmospheric deposition of nitrogen.

Lakes with special characteristics

Phosphorus concentrations have been increasing rapidly in Brændegård Sø, which is home to one of northern Europe's largest cormorant (*Phalacrocorax carbo sinensis*) colonies. Cormorants fish in the coastal waters around Fyn, and via their excrements transport nutrients from these areas to the lake.

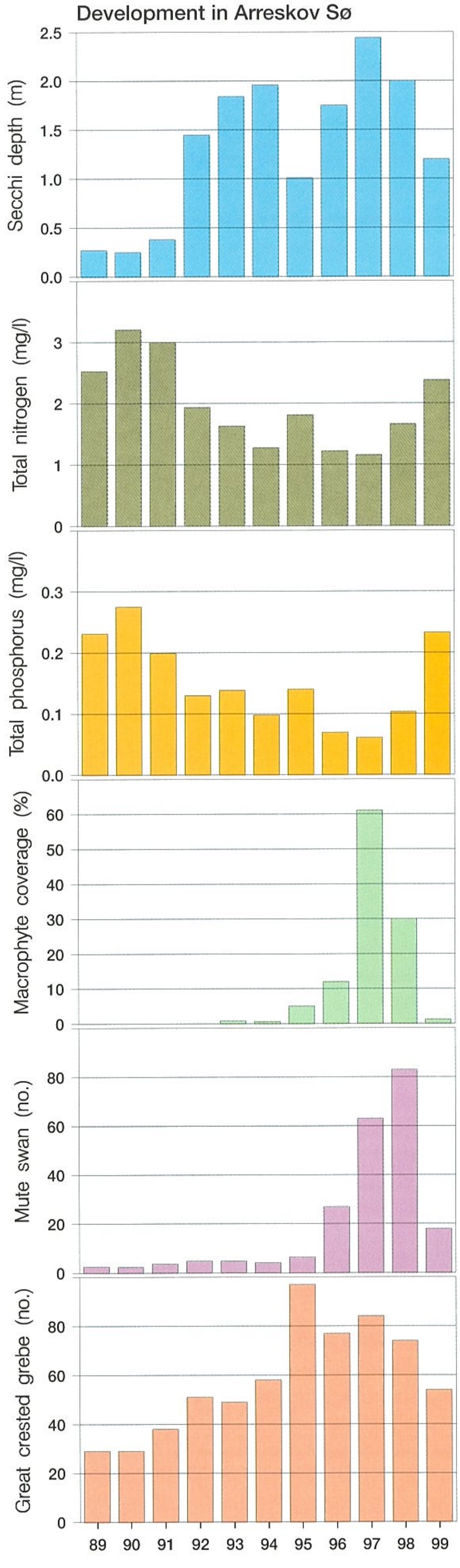


Figure 7.2
Mean values for secchi depth and concentrations of nitrogen and phosphorus in Arreskov Sø during the summer period (May-September) between 1989-1999. Also shown is the proportion of the lake's area covered by submerged plants in July-August, and numbers of mute swans and great crested grebes (annual average) at the lake.

Restoration of lakes using biomanipulation

In situations were the discharge of nutrients to a polluted lake has been limited, improvements in the lake's condition can be accelerated by biomanipulation.

Arreskov Sø

Conditions in Arreskov Sø have changed markedly since discharges of wastewater from the town of Korinth to the lake ceased in 1983. This action reduced by two-thirds the amount of phosphorus entering the lake. There was, however, no marked change in conditions in the lake until 1992, when transparency suddenly improved and nutrient levels decreased. The triggering factor was the disappearance of the majority of the lake's fish, partly because they were removed during winter by a local fisherman and partly due to their death during a period of poor oxygen conditions.

The loss of fish reduced predation on the lake's large daphnids that were able to effectively graze down the planktonic algae. In only a couple of years, summer secchi depth improved nearly eightfold, from 0.25 m to 1.96 m (Figure 7.2). In addition, concentrations of nutrients in the water decreased following the loss of fish, partly because the reduced population of large bream (*Abramis brama*) no longer stirred up the muddy lake bed, and partly because a significant part of the nutrients in the water was incorporated in planktonic algae.

In order to limit the breeding success of roach (*Rutilus rutilus*) and bream, Fyn County Council released piscivorus pike (*Esox lucius*) fry into the lake in 1993 and 1995-1997. Adult bream were also caught and removed in 1995-1997. In both 1995 and 1996, roughly four tons of large bream were caught, though in 1997 the catch fell to 0.6 tons as a result of the significant decline in population size.

Improved water transparency allowed submerged plants to recolonise the lake, so that by summer 1997 61% of the lake bed was covered with vegetation (Figure 7.2). In contrast, there were almost no submerged plants in the lake before 1993.

The numbers of waterfowl species, such as mute swan (*Cygnus olor*) and coot (*Fulica atra*), that feed mainly on aquatic plants increased with the increasing amount of submerged vegetation. The numbers of great crested grebe (*Podiceps cristatus*), which eat fish, also increased, partly because it was easier for them to catch fish in the more transparent water (Figure 7.2).

Conditions in the lake are, however, not stable. In 1999, conditions worsened, as algal abundance

	Søbo Sø 21 ha	Dallund Sø 15 ha	Hvidkilde Sø 61 ha
Bream and roach caught - tonnes	8.3	3.3	11.3
Period	1994-1997	1995-1997	1997-1998
Pike - total number released	115 500	67 500	122 000
Period	1995-1998	1996-1998	1997-1998

Table 7.2
Extent of biomanipulation in three lakes in Fyn County.

increased dramatically and the coverage of submerged vegetation decreased significantly. This resulted in the death of mute swan cygnets, and the number of adult mute swans decreased considerably. Thus, the amount of nutrients entering the lake is still too large to enable clear water conditions to be permanently maintained.

Other biomanipulated lakes

The amount of nutrients entering Dallund Sø, Søbo Sø, and Hvidkilde Sø has decreased over recent years. As a corresponding improvement in conditions in the lakes did not occur, roach and bream were caught and removed, and piscivorus pike fry released into the lakes. The amounts of roach and bream removed and the numbers of pike added are shown in Table 7.2.

These measures have had obvious effects, as the secchi depth in all three lakes increased (Figure 7.3). However, submerged vegetation has not yet begun to recolonise Søbo Sø, and these plants are still scarce in Dallaund Sø and Hvidkilde Sø. If an extensive and stable submerged vegetation does not develop, there is a considerable risk that the lakes will return to conditions of poor transparency and algal blooms.

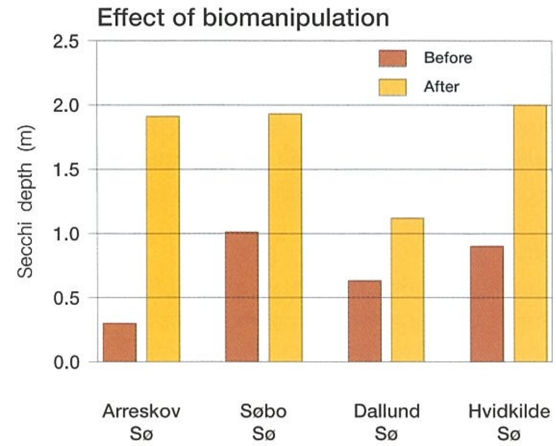


Figure 7.3
Mean secchi depth during the summer period (May-September) before and after biomanipulation measures in four lakes in Fyn County.

Biomanipulation in Søbo Sø. Large bream and other species of fish are caught by seining, and the catch is sorted to determine the numbers of each species.

Photo: Kjeld Sandby Hansen, Fyn County Council

Biomanipulation

Biomanipulation may be used in an attempt to break a cycle of deteriorating environmental quality of polluted lakes. It can, however, only be successfully achieved in shallow lakes into which nutrient input have been limited.

The idea is to improve conditions for the lake's large daphnids. These large members of the zooplankton feed on algae, and filter large volumes of water in order to obtain them. Thus, they efficiently 'clean' lake water and so improve transparency. Fish such as roach and bream, which eat daphnids, are often found in large numbers in polluted lakes. By catching and removing roach and bream fewer daphnids will be eaten. The result is a greater number of large daphnids to eat algae (with conditions becoming more favourable for submerged plants).

Bream also feed on benthic animals, and in searching for them they disturb the lake sediments. This clouds the water and increases its content of nutrients. Thus, the removal of roach and bream often results in improved secchi depth. An additional measure is the release of pike fry into the lake to prey on roach and bream fry. Improved water transparency allows submerged plants to recolonise the lake, giving a good chance that the lake water will remain clear. The long-term success of biomanipulation is dependent on the input of nutrients to the lake being sufficiently low that the concentration of phosphorus in lake water remains under 0.05-0.10 mg/l, presupposing that phosphorus accumulated in the bottom sediments is no longer released into the overlying water (Søndergaard et al., 1998).

Input of nutrients

Since 1989, Fyn County Council has made extensive studies of the input of nutrients to Arreskov Sø, Langesø (extensive monitoring stopped in 1997), and Søholm Sø, as part of the national surveillance programme (NOVA 2003) that was set up to assess the effect of the APAE I and II (see Chapter 2). None of the lakes receive wastewater from towns, the main sources of the nitrogen and phosphorus input being shown in Figure 7.4.

Concentrations of nitrogen and phosphorus in the water of the three lakes are shown in Figure 7.5, along with the levels of these nutrients in selected Danish streams draining 'natural' catchments. The difference between levels in the 'pristine' streams and in the streams feeding the three lakes reflects the amount of nutrients originating from agriculture and scattered homes.

Nitrogen

The major portion of the nitrogen (60 - 82%) entering the lakes is due to agriculture and scattered homes (Figure 7.4). The addition of fertiliser to agricultural land is the primary reason for the considerable leaching of nitrogen from these areas. The 'natural' (i.e. background) contribution of nitrogen is 16-25%, representing the amount of nitrogen that would enter the lakes if no significant human activity took place. For a relatively large lake such as Arreskov Sø, deposition of nutrients from the atmosphere can also make a significant contribution (17%), especially during the summer when input of freshwater to the lake is low.

When the input of nitrogen is adjusted to account for variations in discharge, no general decrease in the amount of nitrogen entering Langesø and Søholm Sø occurred between 1989 and 1998/99, although there appeared to have been a small decrease in Arreskov Sø.

Phosphorus

Human activities in the open land also make a large contribution (37-71%) to the amount of phosphorus entering the lakes, though there is significant variation among the three lakes (Figure 7.4). The contribution from open land is greatest in Langesø, due the large number of farms and scattered homes in the lake's catchment. Studies of a number of streams in Fyn County show that in-stream phosphorus concentration is positively correlated to the density of scattered homes and animals in the catchment (Fyn County, 1997).

Although it remains high, the concentration of phosphorus in the water entering Langesø has been roughly halved between 1989 and 1991, probably due to a reduction in the amount of phosphorus in washing- and cleaning agents used in private households. A similar but smaller reduction in phosphorus levels has occurred in the water entering Arreskov Sø, whereas no change is seen for Søholm Sø, probably because the density of scattered homes in the respective catchments is smaller than in the Langesø catchment.

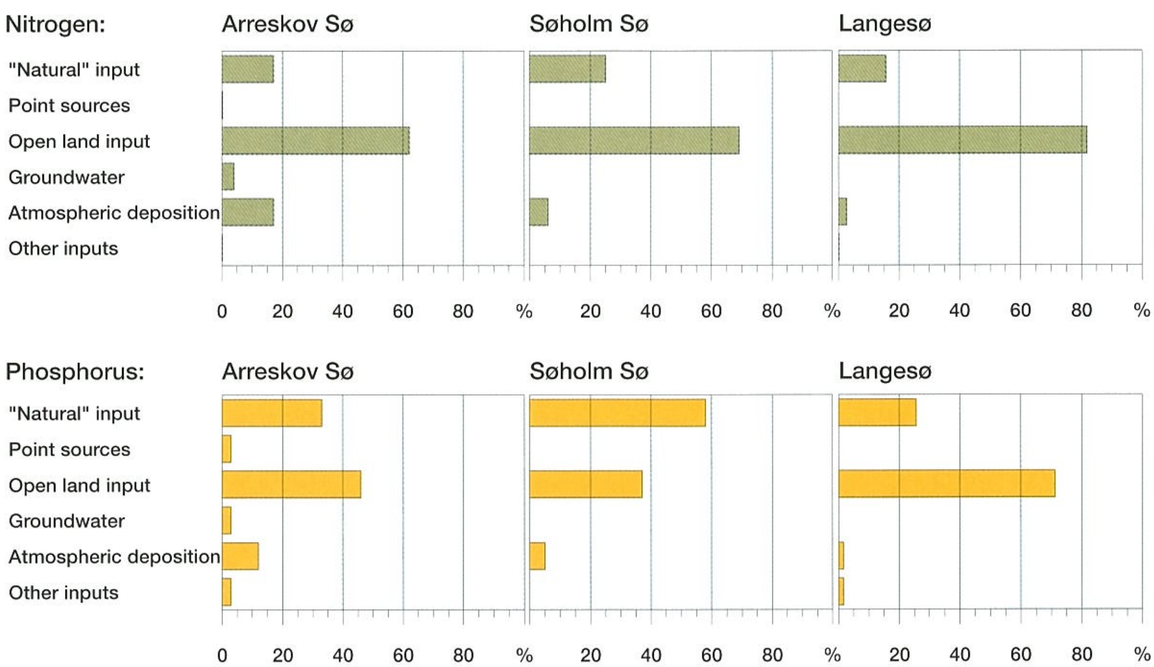


Figure 7.4
Relative contribution of sources of nitrogen and phosphorus inputs to Arreskov Sø and Søholm Sø between 1989-1998, and Langesø between 1989-1997 (mean values for these years). The term "other" refers to sources such as allochthonous leaf litter, ducks, and foraging wild geese.

Retention of nutrients in lakes

A proportion of the nutrients that enter lakes are transformed or deposited. Lakes can retain up to 50-80% of the nitrogen and up to 15-50% of the phosphorus entering them. In this way, lakes serve to reduce the input of these nutrients to the sea.

Cleaner lakes - how ?

Fyn County Council's Regional Plan identifies 34 lakes that should have a natural and varied fauna and flora, and be suitable for recreational and/or commercial fishing. Only four of these lakes currently meet these objectives (Figure 7.6). The remaining lakes are polluted as a result of previous and ongoing input of wastewater and runoff of nutrients from agricultural land.

For the majority of lakes in Fyn, a reduction in phosphorus loading is necessary before condition in them can improve to an acceptable level. In the case of Langesø, it has been estimated that the supply of nutrients resulting from human activities in the open land must be halved, and that the internal release of phosphorus from the sediment must cease. For other lakes, it appears that even a small reduction in the input of phosphorus may result in more stable conditions and clearer water, though such a development may require some time.

A reduction in the input of nitrogen is also expected to improve conditions in many lakes, as the availability of nitrogen, at least in certain periods of the year, limits the growth of algae.

Measures to reduce inputs of nutrients to the lakes in Fyn include improving the treatment of wastewater from scattered homes and limiting the loss of nutrients from agricultural land.

The Regional Plan requires the discharge of wastewater from scattered houses in the catchments of most lakes to be limited by the end of 2002. Please refer to Chapter 2 for a discussion of the national and regional action plans for reducing nutrient loading of the aquatic environment.

In order to coordinate and increase efforts to improve conditions in its lakes, Fyn County Council intends to produce action plans for selected lakes that encompass all human activities in the catchments.

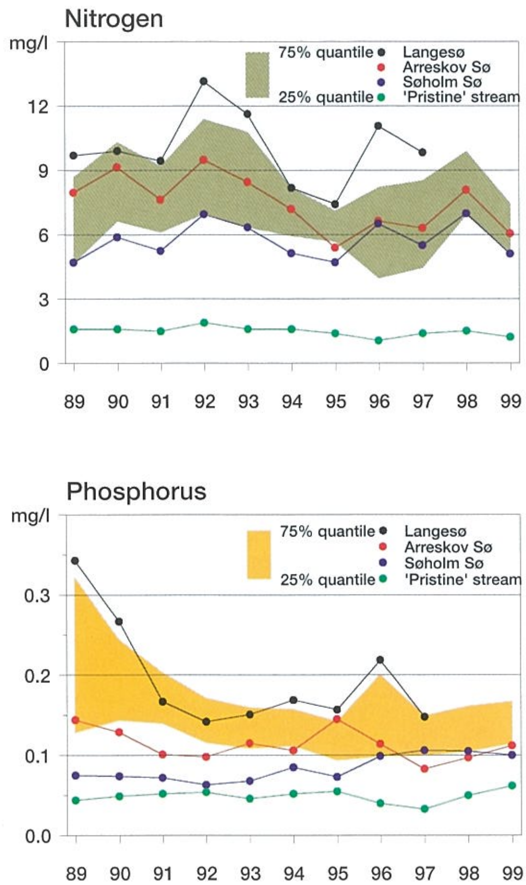
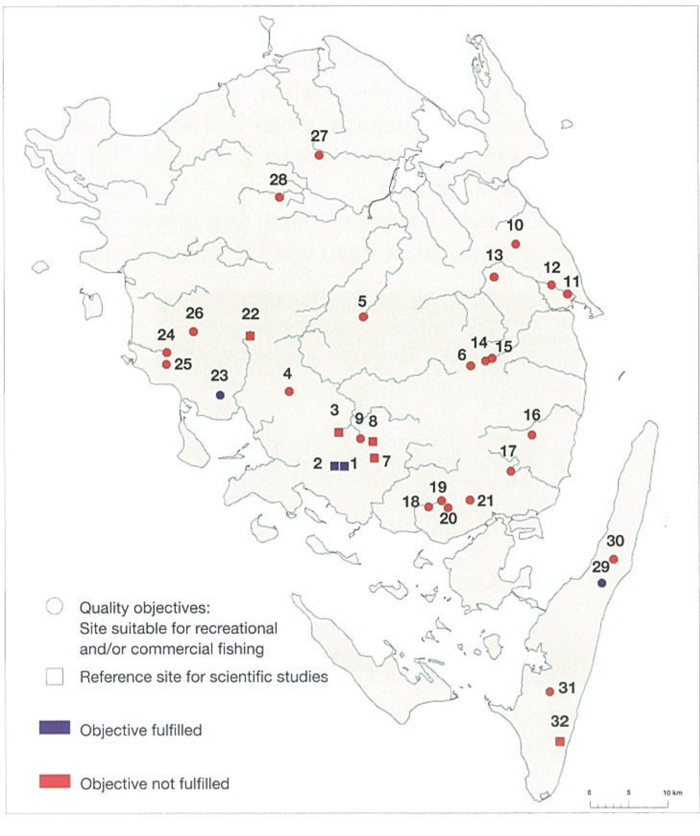


Figure 7.5
Mean annual concentrations of nitrogen and phosphorus (corrected for discharge) in the streams entering Arreskov Sø, Langesø, and Søholm Sø. For comparison, the concentrations of nitrogen and phosphorus in Danish streams draining 'natural' catchments (means for 5-7 streams) are shown. The 25% and 75% quantiles for monitored streams in Fyn County are indicated by the solid band, i.e. half the streams have nitrogen and phosphorus concentrations within the upper and lower values.

Figure 7.6
Location of the 34 lakes in Fyn County for which water quality objectives have been set, and indication of whether the objectives have been met.



1. Sortesø
2. Store Øresø
3. Arreskov Sø
4. Søbo Sø
5. Nr. Søby Sø
6. Fjellerup Sø
7. Brændegård Sø
8. Nørresø
9. Brahetrolleborg Slotssø
10. Flødstrup Sø
11. Ladegård Sø
12. Hjulby Sø
13. Vomme Sø
14. Kobbermose
15. Gammelmølle Sø
16. Gudme Sø
17. Holmdrup Mose
18. Ollerup Sø
19. Nielstrup Sø
20. Hvidkilde Sø
21. Sørup Sø
22. Søholm Sø
23. Sarup Sø
24. Nordby Sø
25. Sønderby Sø
26. Sdr. Søby Sø
27. Dallund Sø
28. Langesø
29. Stengade Sø (2 basins)
30. Tranekær Borgsø
31. Hannebjerg Mose (2 basins)
32. Sædballe Fredmose

Helnæs Bugt Photo: Bert Wiklund

8 Coastal Waters

Fyn County comprises some 90 islands and thus has a considerable length of coastline: approx. 1 100 km in total. This is equivalent to 0.33 km of coastline per km^2 land, compared to 0.17 km/km^2 for Denmark as a whole.

Fyn's coastal waters comprise many different types of marine areas, from open coastal waters and channels of significant depth, to extensive shallow-water regions, and enclosed fjords and coves. The tidal range is typically small, some 25 cm on northern Fyn and 5 cm on the southern coast of the island of Ærø. Strong winds can, however, alter the normal range by more than a metre.

The construction of dikes, embankments, and drainage channels in order to reclaim land has significantly reduced the number and total area of fjords and coves since the middle of the 1800s (see Chapter 1). Since the last Ice Age, northern Fyn has risen by roughly a metre while southern Fyn has sunk, so that the South Fyn Archipelago, a flooded ice age landscape, has sunk by more than three metres since the Stone Age.

Table 8.1
Riverine runoff of nitrogen and phosphorus from Fyn County to the surrounding coastal waters between 1996 and 1999, compared to the average runoff between 1976 and 1987, a period prior to implementation of the Action Plan for the Aquatic Environment I. Also shown are mean values for the period 1992-1999.

Riverine runoff from Fyn	Nitrogen tons/yr	Phosphorus tons/yr
Mean, 1976-87	9 234	674
Mean, 1992-99	7 700	206
1996	2 975	100
% change compared to 1976-87	-68%	-85%
1997	3 183	98
% change compared to 1976-87	-66%	-85%
1998	10 215	241
% change compared to 1976-87	+11%	-69%
1999	8 366	246
% change compared to 1976-87	-9%	-64%

Inputs of nitrogen and phosphorus to coastal waters

Environmental conditions in the waters around Fyn are affected by the addition of nitrogen and phosphorus from land, the atmosphere, and the surrounding marine environment. During the surveillance period 1976-1999, phosphorus loading from land has decreased significantly, primarily as a result of intensive wastewater treatment. In contrast, nitrogen loading from the land has varied considerably from year-to-year without showing a notable downward trend. This is despite there being evidence for a 20-25% reduction in the precipitation-normalised input of nitrogen to coastal waters in recent years due to improved wastewater treatment and measures to control the impact of agriculture on the environment (Chapter 5).

In 1996-1997, loading from the land was unusually low, due to long periods with lower than normal precipitation (Table 8.1). In these two years the goals of a 50% reduction in nitrogen input and an 80% reduction in phosphorus input, set out in the Action Plan for the Aquatic Environment I, were met for the first time since the plan's enactment in 1987. In 1998, and again in 1999, precipitation was higher than normal (see Chapter 4), causing the runoff of nitrogen especially to rise again.

Atmospheric deposition of nutrients makes a significant contribution of nitrogen and phosphorus to coastal waters. In the Kattegat and Belt Sea atmospheric deposition accounts for some 30% of land-based nitrogen loading in a normal year. During the summer, when runoff from land is low, atmospheric deposition can be the primary source of nutrients entering coastal waters (Ærtebjerg et al., 1998).

Environmental conditions in coastal waters

Surveillance of the coastal waters around Fyn includes electronic profiling of hydrographic variables such as salinity and temperature, as well as oxygen levels and algal abundance (chlorophyll fluorescence); collection of water samples for analysis of nutrients, phytoplankton (chlorophyll and primary production), and oxygen levels; and examination of sediments, and benthic plants and animals. These activities are carried out in deeper, coastal waters and shallow, nearshore waters. Locations of the sampling stations in coastal waters and fjords in 1998, the first year of the new NOVA 2003 monitoring programme (described in Chapter 3), are shown in Figure 8.1. The stations specifically discussed in this chapter are highlighted.

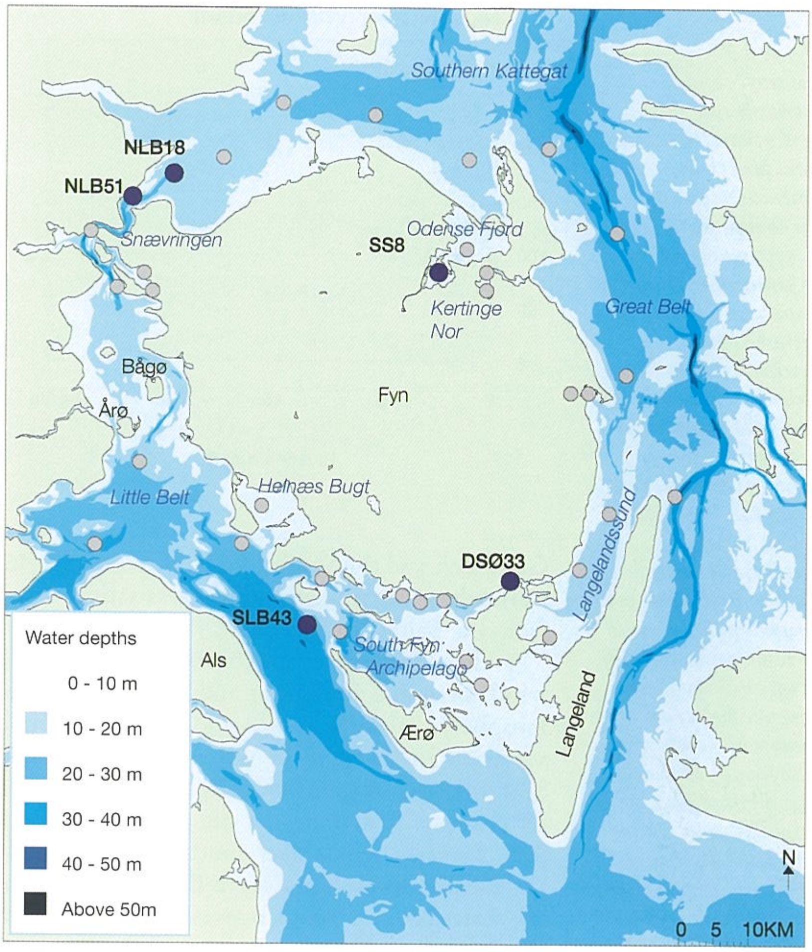


Figure 8.1
Fyn County Council's monitoring stations for pelagic measurements in the open coastal waters around Fyn County in 1998, the first year of the NOVA 2003 programme (see Chapter 3). Also shown are the location of stations SLB43, NLB51, NLB18, DSØ33, and SS8 that are discussed in this chapter.

Hydrographic conditions

The water masses in the Belt Sea are typically stratified, with light, relatively fresh water from the Baltic Sea at the surface, and heavier, more saline water from the Kattegat near the bottom (Figure 8.2). The stratification is strengthened by temperature differences between surface and bottom layers, creating a pycnocline. This layering is most marked during the summer half of the year, and has important implications for the growth of phytoplankton and for oxygen levels in the bottom waters. The salinity of the surface waters during the summer is highest to the north of Fyn (17-21 psu), and lowest in the southern part of the

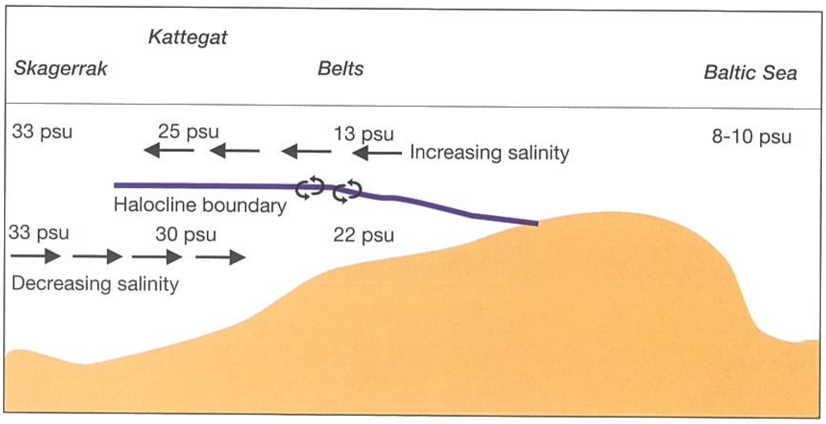
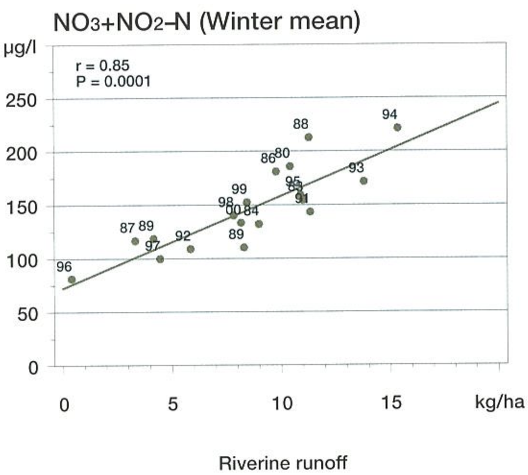


Figure 8.2
Sketch of the basic flow and stratification of water masses in Denmark's inner coastal waters (redrawn from Fyn County, 1990). The average salinities of the water masses (given in psu, equivalent to the previously-used unit ‰) during the summer (July-September, 1976-1983) are shown.



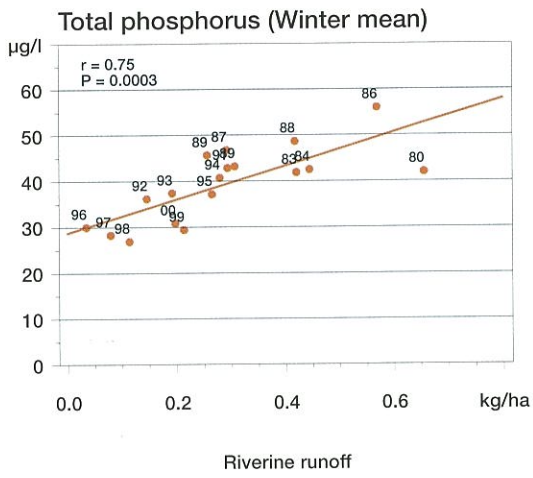
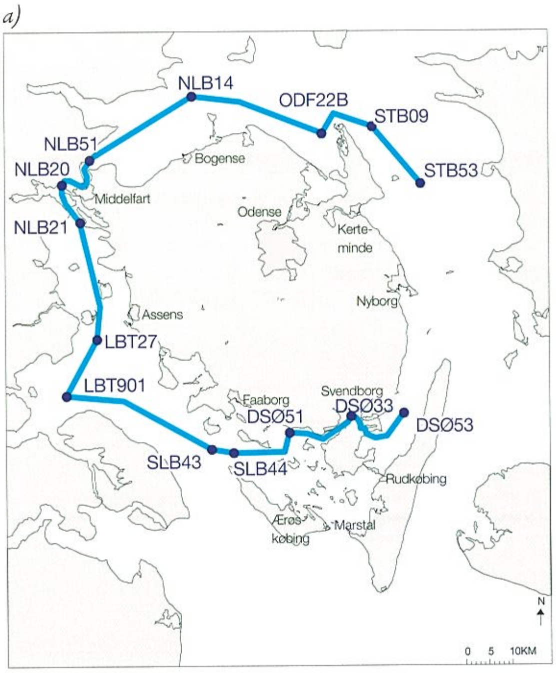


Figure 8.3 Nitrate-N and nitrite-N concentrations (left) and total phosphorus concentrations (right) in the coastal waters (1 m depth) around Fyn in January-February as respective functions of nitrate-N and nitrite-N output from Odense Å at Kratholm, and total phosphorus runoff from Fyn County (1979/80 and 1982/83-1999/00), in kg/ha during December-January. Each coastal water concentration is the mean of 12-68 measurements at up to 13 stations. The winter period represented by each value is shown by the last two digits of the two calendar years during which the data were collected, e.g. the winter December 1999 to January 2000 is indicated by '00'.

Great Belt and the South Fyn Archipelago (13-16 psu), where the influence of the less-saline water from the Baltic Sea is greatest.

As the tidal range of the coastal waters is small, wind force and direction, and variations in atmospheric pressure are, in addition to seasonal variation in the flow of water from the Baltic Sea, primarily responsible for generating the water currents that transport nutrients in the Belt Sea. Westerly winds over southern Scandinavia and Denmark result in a south-flowing current in the Kattegat, and water masses are pushed into the Baltic Sea. This causes water in the Kattegat to move further south, increasing salinity in the Great Belt. In contrast, easterly winds increase the flow of water from the Baltic Sea, and the northward flow of water in the Kattegat, causing salinity in the Great Belt to fall. Exchange of the bottom water in the deep part of the Little Belt, south of the shelf between the islands of Årø and Bågø, is dependent on salinity changes

a)



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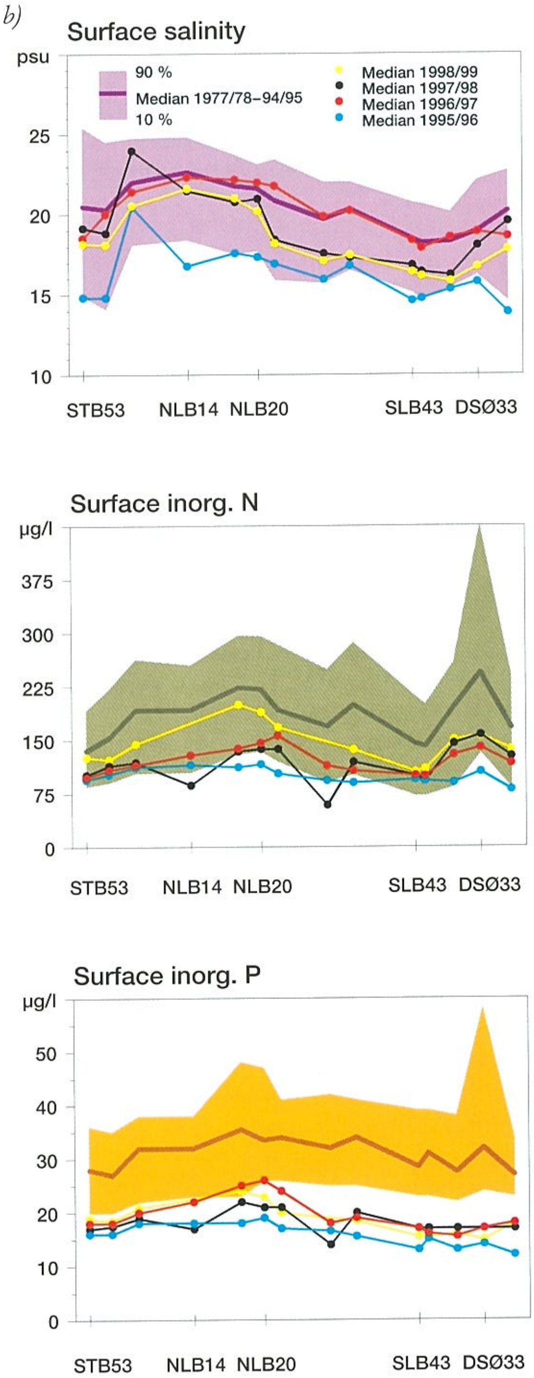

Figure 8.4 (a-d)

a) Transect from the Great Belt (beginning at station STB53), through Snævringen and Little Belt, to the South Fyn Archipelago and ending at DSØ53 in Langelandssund.

b) Median salinity, nitrogen, and phosphorus concentrations in surface waters (1 m depth) over the winter months (Dec.-Feb.) between 1995/96 and 1998/99.
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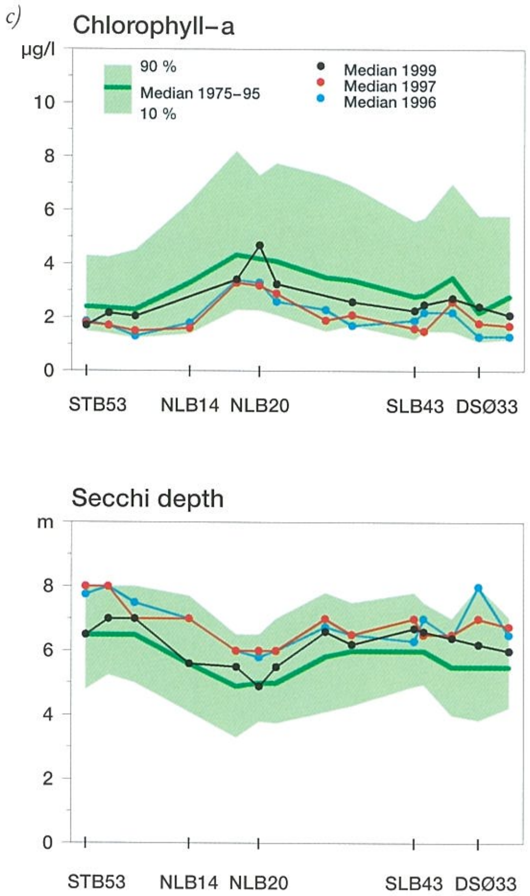
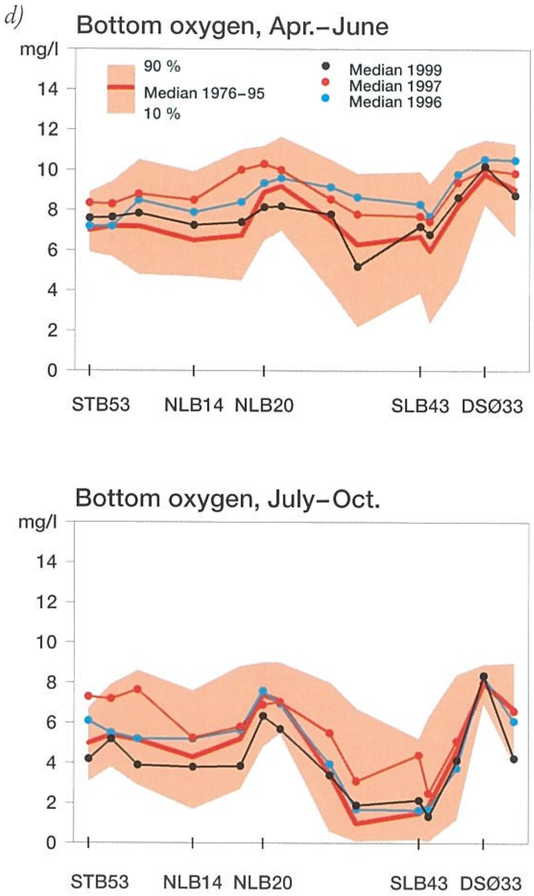




c) Median chlorophyll-a concentrations (1 m depth) and secchi depth during the summer months (May-Sept.) in 1996-1997 and 1999.

d) Median oxygen content of bottom waters in the spring months (April-June) and autumn months (July - Oct.) in 1996-97 and 1999.

Medians are shown along with 10% and 90% quantiles for the period 1977/78 to 1995/96 or the period 1975-1995, as appropriate.

in the Great Belt and Langelandssund, and so is also greatly affected by wind conditions.

Whereas salinity differences are the major determinant for the stratification of the watercolumn, warm, calm periods during the summer intensify the layering and so increase the likelihood of oxygen depletion developing. The summers of 1994, 1995, and 1997 were unusually sunny and warm, and in August 1997 both air and water temperatures reached record high levels. In contrast, the summer of 1998 was more wet, windy, and cold than normal, whereas the summer of 1999 was both wet and relatively warm.

During winters that are sufficiently cold that the sea ices over, mixing of water masses is reduced. During the last decade or so, large parts of Fyn's coastal waters were covered with ice in the winters of 1986/87, 1995/96 and, for a brief period, in 1996/97.

Nitrogen and phosphorus

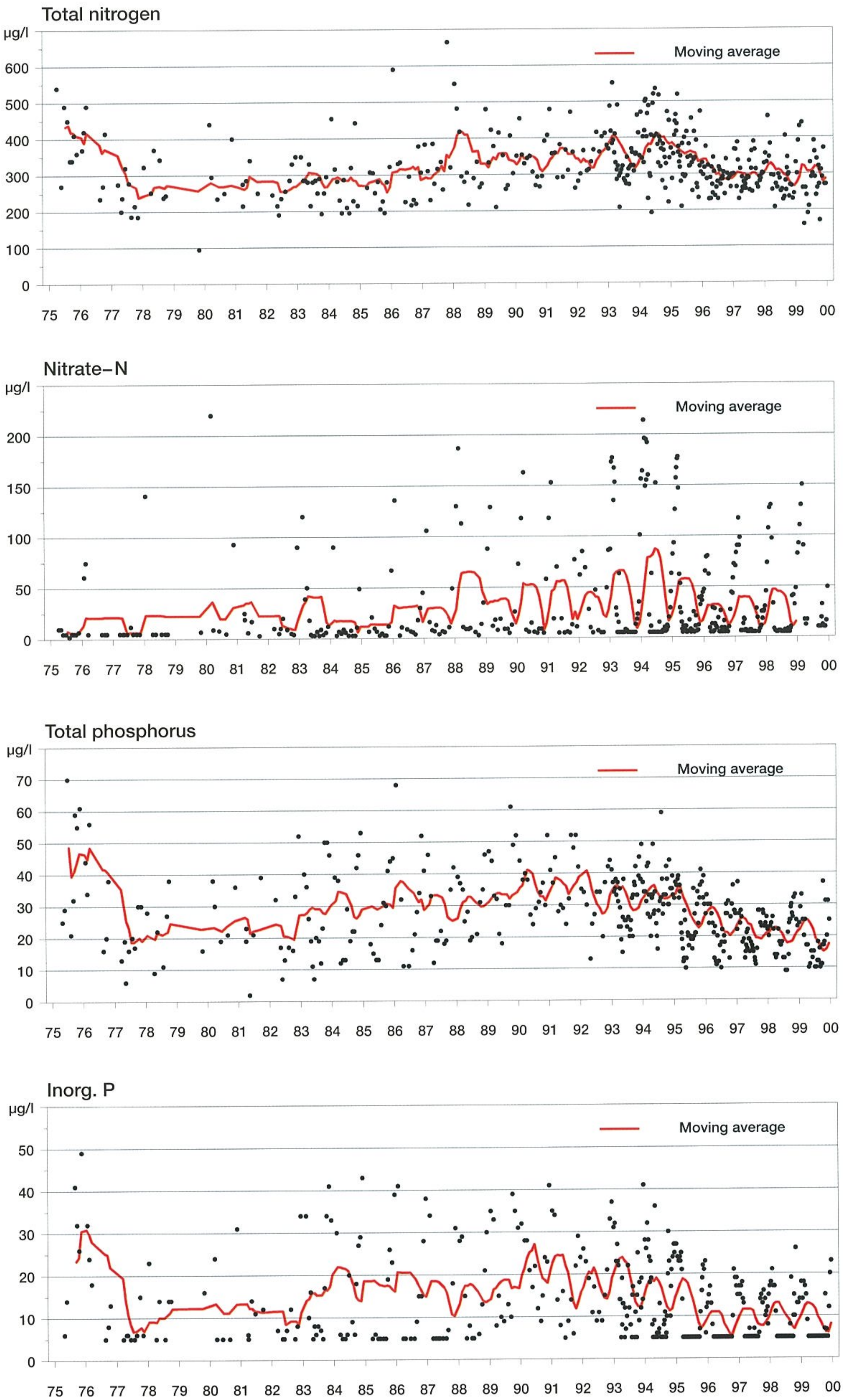
For both nitrogen and phosphorus there is a good relationship during the winter between runoff from the land and concentrations in coastal waters (Figure 8.3).

The concentration of phosphorus in surface waters during the winter has fallen significantly during the period 1976-97, in parallel with reduced loading from the land. The concentration of nitrogen in surface waters has shown no clear trend, having varied considerably from year-to-year depending on loading from the land. The highest concentrations of nitrogen in surface waters were measured in 1980, 1988, and 1994, in which years loading from the land was very high, whereas concentrations in 1996 and 1997 were among the lowest during the whole surveillance period. In 1998-1999, the concentration of nitrogen in the coastal waters increased again as a result of increased runoff from the land (Figure 8.3 and 8.4b). Nitrogen concentrations in Denmark's inner coastal waters were, in general, higher in 1999 than during the preceding three years (Statistics Denmark, 2000b).

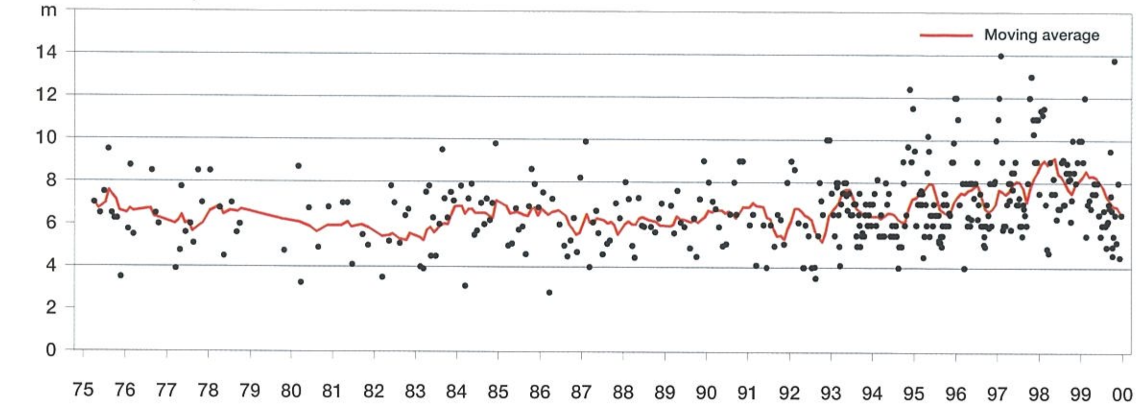
Phytoplankton

Microscopic algae - phytoplankton - that float freely in water masses produce organic substances out of simple nutrients, inorganic carbon, and light. The growth of phytoplankton is partly dependent on the addition of nutrient to water masses. In areas near the coast, phytoplankton growth is typically limited by phosphorus levels in the spring and nitrogen levels during the summer (Conley, 1998). The first measurements of phytoplankton growth in Danish waters began in the Kattegat in the 1950s, and since then the primary production of phytoplankton has nearly

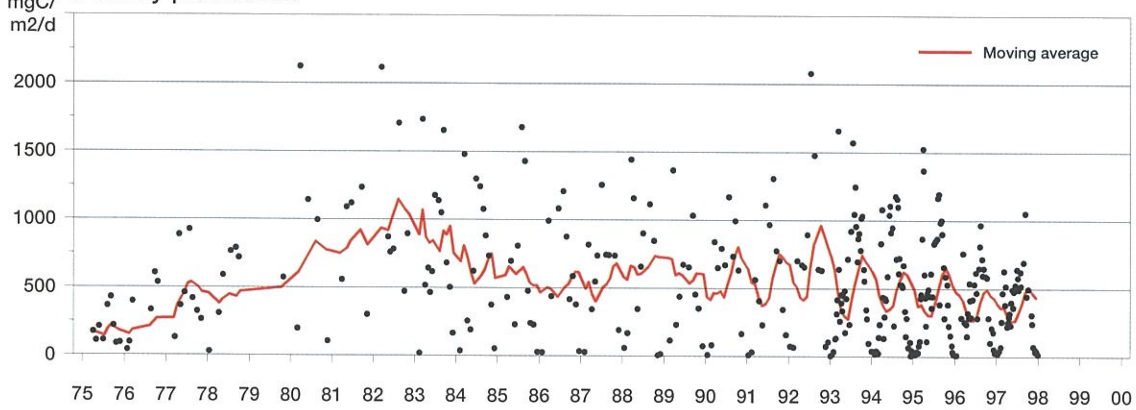
Figure 8.5
Surface water nutrient concentrations (1 m depth), visibility (secchi depth), primary production, and oxygen levels in the bottom water (for the latter only measurements for the spring and summer periods are presented) at station SLB43 in the southern Little Belt during 1975-1999. Using the monthly mean values, seven-month moving averages have been calculated (with the exception of the last two figures presenting oxygen levels). Note that the amount of data prior to the beginning of the 1980s is limited. Nitrate measurements for the period 1 May - 1 Sept. 1999 are not presented, due to analytical problems, and moving averages, therefore, not calculated.



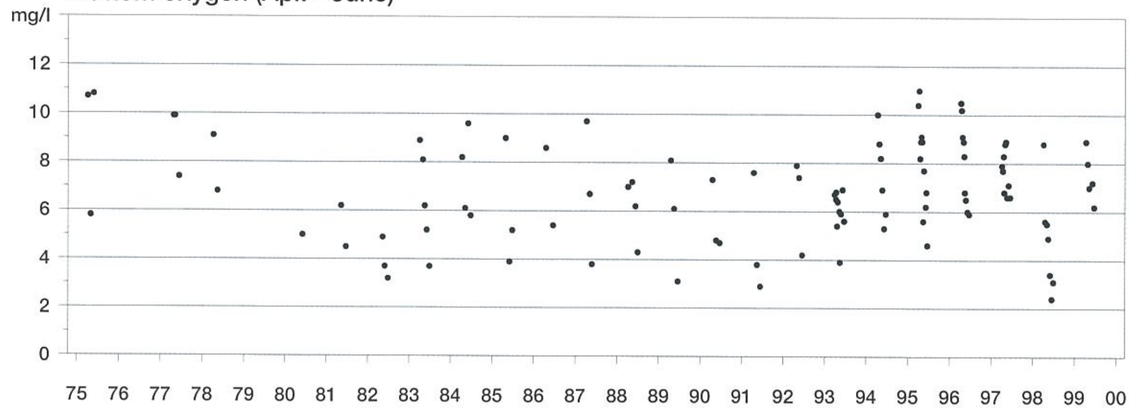
Secchi depth



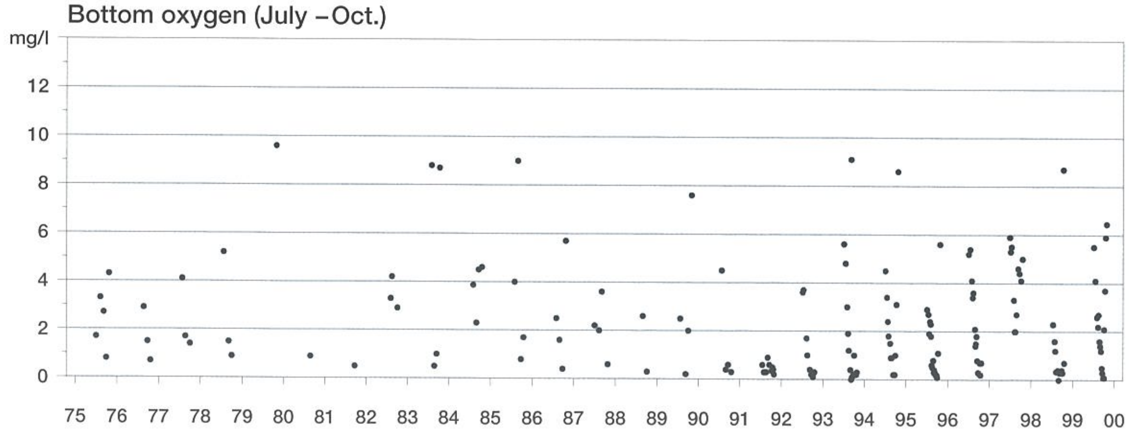
Primary production



Bottom oxygen (Apr. – June)



Bottom oxygen (July – Oct.)



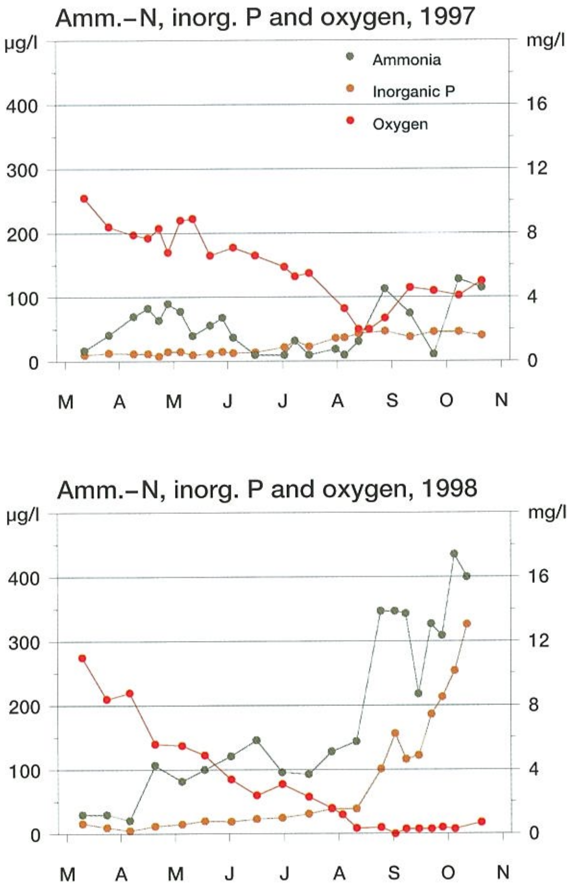


Figure 8.6 Concentrations of oxygen (mg/l), ammonium and ortho-phosphate (µg/l) in bottom waters at the approx. 35 m-deep station SLB43 in the southern Little Belt in 1997 (upper) and 1998 (lower). The serious oxygen depletion in 1998 resulted, from the beginning of August, in a prolonged release of ammonium and ortho-phosphate from the sediments. In comparison, oxygen depletion in 1997 was of a more limited extent and release of nutrients from the sediment was low.

doubled (Richardson & Heilmann, 1995). Measurement of phytoplankton in Fyn's coastal waters began in 1975. Especially high rates of phytoplankton growth and biomass were measured in the early 1980s and 1990s (Figure 8.5), following periods of considerable loading from the land. These observations agree well with general tendencies in Denmark's inner coastal waters (Ærtebjerg et al., 1998). The general trend of falling phosphorus concentrations since the beginning of the 1990s has, however, gradually reduced the potential for phytoplankton growth in fjords during the spring (Conley et al., 2000).

Reduced nutrient loading, and correspondingly low nutrient concentrations in water, during the summers of 1996 and 1997 resulted in unusually low phytoplankton growth and thus good visibility in Fyn's coastal waters (Figure 8.4c and 8.5). Following increased nutrient loading in 1999, the abundance of phytoplankton again increased in the coastal waters in general. In the eastern and southern part of Denmark's inner coastal waters in particular, blooms of cyanobacteria and dinoflagellates occurred, resulting in the issue of warnings against bathing (NERI, 1999).

In warm, calm periods during summer the release of nutrients from sediment increases in shallow waters. In deeper waters, longer periods of oxygen depletion also cause release of nutrients to bottom waters (e.g. as shown in Figure 8.6). The release of nutrients stimulates new algal growth, often in the water column near the pycnocline.

Toxic algae

Many species of algae produce toxic substances. Species of the dinoflagellate, *Dinophysis*, are filtered from seawater by common mussels, and when present even in relatively small numbers can poison humans that eat common mussels. The blue mussel fishery in the Little Belt is regularly closed due to the presence of these algae. Other types of algae, for example certain cyanobacteria, prymnesiophytes, and dinoflagellates can, when present in very large numbers, also poison benthic animals and fish, and humans who come in contact with the algae.

Oxygen conditions

Oxygen depletion in bottom waters is a natural occurrence, though the extent and duration of oxygen depletion are increased by the addition of organic matter. Increased phytoplankton growth results in the addition of greater amounts of organic material to bottom waters, so increasing the likelihood of oxygen depletion developing. In the summer of 1981 the first case of extensive oxygen depletion, with associated mortality of fish in Denmark's inner coastal waters, was registered. A large number of fish also died in Fyn's coastal waters as a result of oxygen depletion, and in most years since, oxygen depletion has occurred in a large part of Fyn's coastal waters. Historical benthic animal data, collected by the Danish Biological Station in the southern Little Belt during 1910-30, showed that oxygen depletion then only occurred at depths of more than 30 m to the north of Als, and at depths of more than 35 m in the channels between Als and Ærø. Today the depths at which oxygen depletion occurs in these areas have decreased to 20 m and 30 m, respectively. The area of the Little Belt in which oxygen depletion frequently occurs has increased by roughly fivefold (Figures 8.7 and 8.8).

As a result of low phytoplankton growth, and a correspondingly low production of organic material, unusually good oxygen conditions prevailed during the summers of 1996-1997 (Figures 8.4d, 8.5, and 8.7).

In 1997, oxygen depletion was primarily confined to the southern Little Belt where, for natural reasons, conditions conducive to oxygen depletion readily develop (Figure 8.7). During the summers of 1998, 1999, and 2000, oxygen conditions again worsened, and almost all Fyn's coastal waters were affected by oxygen depletion (Figure 8.7). In 1998, windy and relatively cold summer weather limited the development of oxygen depletion in more shallow waters (Fyn County, 1999a). In contrast, the warm late summer of 1999 resulted in widespread and extensive oxygen depletion, with the release of hydrogen sulphide at many locations, including shallow waters (Fyn County, 2000c). In many parts of Denmark's inner coastal waters, e.g. the Limfjord, Århus Bay, and many of the fjords in eastern Jylland, extensive mortality of benthic animals occurred in 1999 (DEPA, 1999). Extensive, serious oxygen depletion also occurred in 2000. Already by mid August unusually extensive oxygen depletion had developed in Fyn's coastal waters, resulting in mortality of benthic animals at some locations. In the Great Belt, oxygen levels were historically low in 2000.

Oxygen depletion

When the concentration of oxygen in a water mass falls to less than 4 mg/l the term 'oxygen depletion' is applied. Many species of fish will try to flee such conditions. When the oxygen concentration falls to less than 2 mg/l, oxygen depletion may be considered serious. A prolonged period of serious oxygen depletion will eventually kill the majority of benthic animals that cannot escape the area. A common indicator of oxygen depletion is a layer of white sulphur bacteria on the sea bed. During particularly serious and long periods of oxygen depletion, hydrogen sulphide (H_2S) is eventually released from the sediment to the bottom waters. Hydrogen sulphide will quickly poison most animals and higher plants that require oxygen to respire.

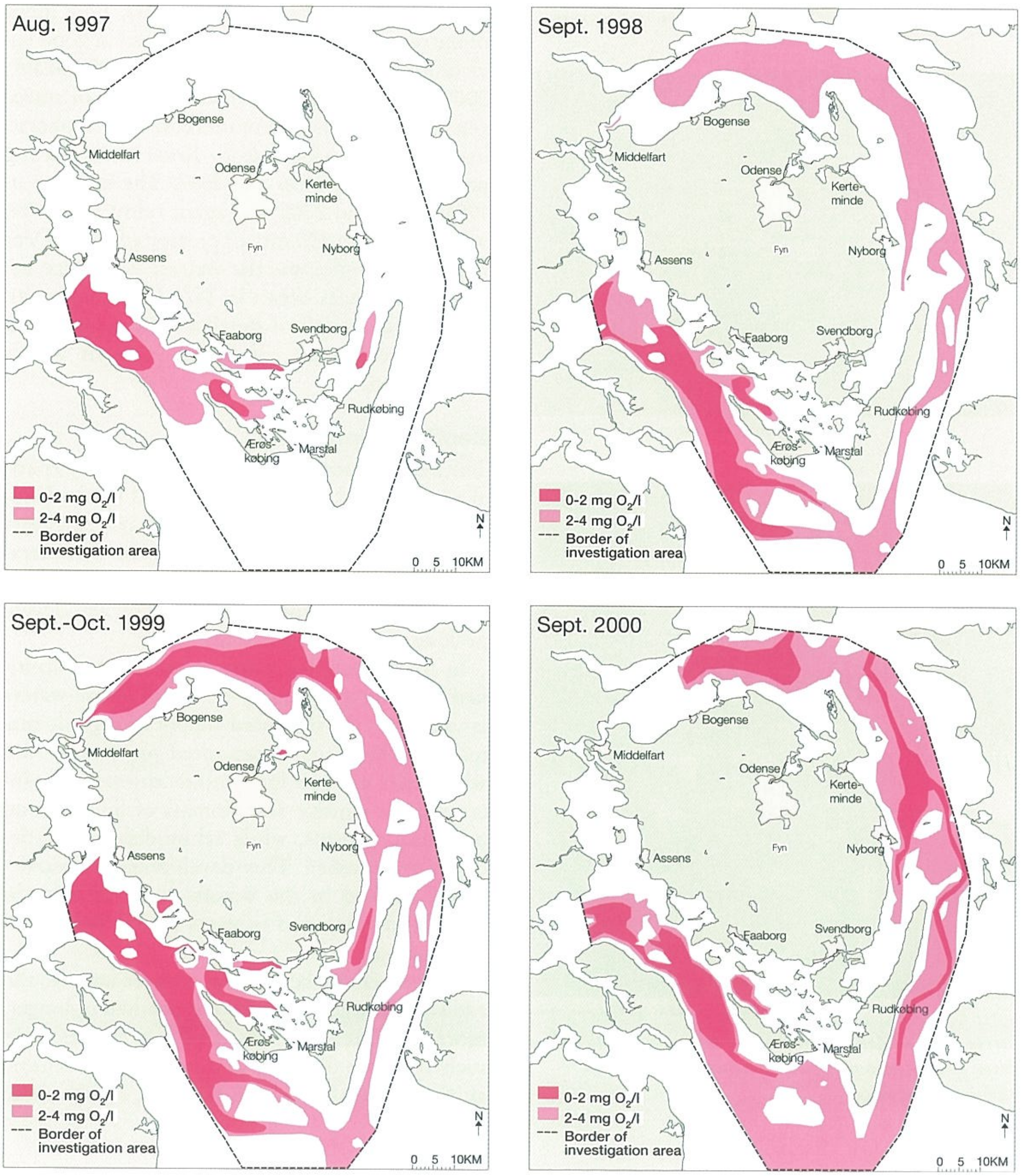


Figure 8.7
Oxygen depletion during the period 1997-2000.

Photo: Nanna Rask, Fyn County Council

Release of hydrogen sulphide from sediments to the water in an eelgrass meadow, at roughly 4 m depth, during a period of oxygen depletion in the small cove Lindelse Nor in the South Fyn Archipelago. Hydrogen sulphide oxidises to free sulphur on contact with oxygen in the water. The free sulphur is seen as grey clouds above the sea bed. Eelgrass is sensitive to hydrogen sulphide. Thus, oxygen depletion can result in extensive death of eelgrass, e.g. as seen in the South Fyn Archipelago during the warm summer of 1994, when eelgrass disappeared from over half the area in which it previously grew.

Photo: Søren Larsen, Fyn County Council

Dead fish in the shallow Dalby Bay on northern Fyn after the first documented episode of oxygen depletion in Danish coastal waters during the summer of 1981.

Photo: Nanna Rask, Fyn County Council

Growth of white sulphur bacteria on black (anoxic) sediments between colonies of common mussels during a period of oxygen depletion at roughly 11 m depth in Nakkebølle Fjord in the South Fyn Archipelago.

In summary, data collected for the surveillance period 1976-2000 show good overall relationships between nutrient loading, nutrient concentrations in sea water, algal growth, and oxygen depletion in Fyn's open coastal waters. Low input of nutrients in 1996 and 1997 resulted in good environmental conditions (Rask et al., 1999; DEPA, 2000c). However, the reduced loading of nitrogen and part of the recent decrease in phosphorus loading, are attributable to lower than normal precipitation in 1996 and 1997. The weather in 1998, 1999, and 2000 was again rainy, and 1999, with more than 900 mm of precipitation for Denmark as a whole, was the wettest year since nationwide records began in 1874 (see Chapter 4). As a result, runoff of nutrients increased again, and environmental conditions in open waters deteriorated.

Benthic animals

The benthic fauna and vegetation in many coastal areas around Fyn were examined by the Danish Biological Station during 1880-1930. Benthic animal communities have undergone considerable changes between then and now as a result of nutrient loading and more frequent and severe periods of oxygen depletion.

In areas where the water masses are not stratified, and oxygen supply to the bottom waters is sufficient, the increased supply of organic material in the form of deposited phytoplankton, which acts as food for benthic animals, has increased the density and biomass of bivalves and polychaete worms, while echinoderms have declined in number. This development is particularly marked in the waters north of Fyn, in Langelandssund, and in parts of the South Fyn Archipelago.

In areas where the water masses are layered, the addition of organic matter has resulted in longer, more widespread periods of oxygen depletion. In such areas the diversity and numbers of benthic animal species have been reduced, and in some areas benthic animals have disappeared completely due to chronic oxygen depletion. In the deep areas of the southern Little Belt and the South Fyn Archipelago, benthic animals have been affected by annual oxygen depletion. At these locations the benthic fauna is dominated by only a few species that can tolerate oxygen depletion and utilise the abundance of organic matter. The numbers of individuals present are typically low and in some years no animals are present. Large areas of the Little Belt and the waters north of Fyn, which were not subject to oxygen depletion at the beginning of the 1900s, are now frequently affected. As a result, the communities of benthic animals at these locations have changed character completely (Figure 8.8).

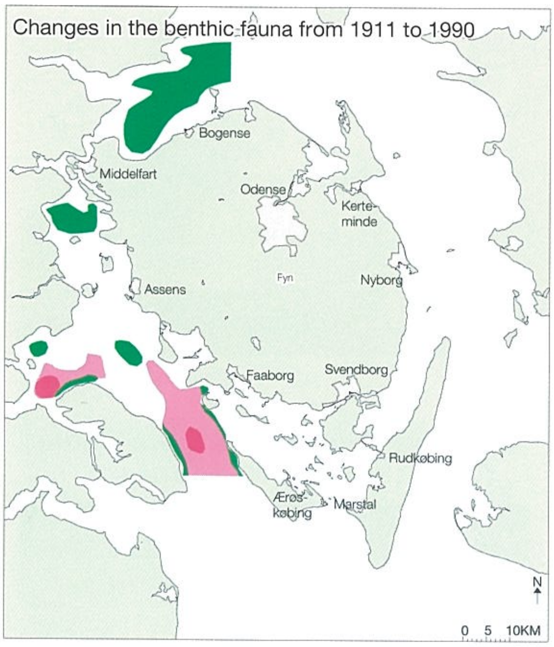
Good oxygen conditions in 1996 and 1997 allowed oxygen-sensitive benthic animals to recover at many of the locations in Langelandssund and southern Little Belt where the fauna where significantly reduced or completely killed-off by previous periods of oxygen depletion. In 1998, however, extensive oxygen depletion again occurred, and the release of toxic hydrogen sulphide from the sediment was recorded in the southern Little Belt. The poor conditions resulted in benthic animals again disappearing from a large part of the area in 1998. In 1999 and 2000, as mentioned previously, oxygen depletion caused the death of benthic animals at many locations.

Photo: Nanna Rask, Fyn County Council

Mats of the purple cyanobacteria, Spirulina subsalsa, *cover large areas of the southern Little Belt and the South Fyn Archipelago, coating the sea bed and algae growing on stones. Under the mats of* Spirulina *the sediment surface is often black and anoxic.*

Photo: Nanna Rask, Fyn County Council

Layers of purple sulphur bacteria cover the sea bed and vegetation in shallow waters (0.8 m depth) in Lindelse Nor in the South Fyn Archipelago during August 1997. Growth of purple sulphur bacteria on the sea bed indicates that the oxic-anoxic interface has moved all the way up to the sediment surface. Observations during aerial photography revealed that large areas of the sea bed around southern Fyn were covered with purple sulphur bacteria during the summer of 1997. Water temperatures reached record high levels during the warm, calm month of August, and in some shallow-water areas oxygen depletion and the phenomenon of "the bottom turning upside-down" (i.e. when ebullition of methane gas bubbles tear off fragments of the sediment surface) occurred whereas unusually good oxygen conditions prevailed in deeper waters.



Legend:

- "Enriched" benthic fauna - by increased input of organic matter
- "Impoverished" benthic fauna - by increased hypoxia/anoxia
- No benthic fauna - "natural" oxygen depletion areas

Figure 8.8 (left)
Extent of the areas in the Little Belt where the benthic fauna has changed as a result of increased input of organic material and increasing extent of oxygen depletion, together with areas affected by oxygen depletion during the periods 1910-30 and 1973-88. The comparison is based on the benthic fauna sampled in 1910-30 and 1973-88, respectively.

Benthic vegetation

The extensive shallow, sandy-bottomed areas in the coastal waters around Fyn are colonised by meadows of eelgrass (*Zostera marina*) and other seagrasses. In stony and hard-bottomed areas macroalgae predominate, with brown algae dominant in northern areas, and red algae in southern and eastern areas, where the salinity is lower.

The distribution and composition of benthic vegetation in Fyn's coastal waters have changed considerably during the last 100 years. The Danish Biological Station surveyed eelgrass and macroalgae in Denmark's inner costal waters at the beginning of the 1900s (Ostenfeld, 1908; Kolderup-Rosenvinge, 1909). Conditions in the central part of the Little Belt and adjoining fjords were mapped in 1889-1890 (Figure 8.9) and were followed by mapping of sets of eel traps and the distribution of eelgrass in Denmark's inner costal waters (Figure 8.10). In 1933-34 the eelgrass disease caused eelgrass to disappear from the majority of Denmark's inner costal waters (Petersen, 1935). It has since returned, but has not colonised to the same depths as before. Thus, in many areas the present depth distribution of eelgrass is roughly half of that at the turn of the century. In fjords, the reduction in depth distribution has been even greater, resulting in a considerable reduction in the area covered by eelgrass (Rask et

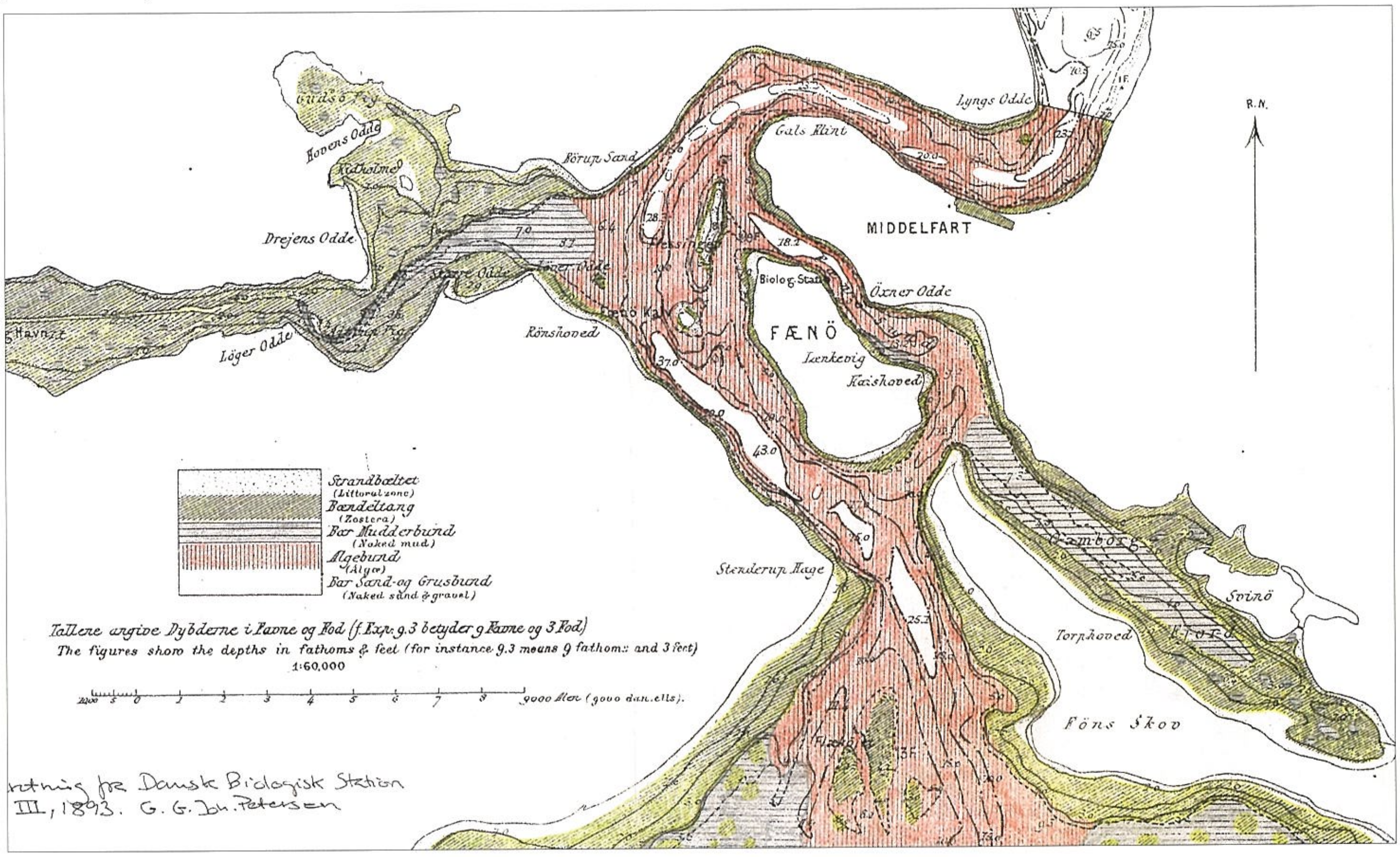


Figure 8.9
Distribution of eelgrass (green) and macroalgae (red) in Snævringen in the Little Belt, and in the adjoining Kolding Fjord and Gamborg Fjord in 1889 (Petersen, 1892).

Distribution of eelgrass

At the beginning of the 1900s, eelgrass meadows covered the majority of the sea bed in the fjords and shallow-water areas around Fyn County. In the 1930s, eelgrass disease greatly reduced the distribution of eelgrass. The reduction was greatest in areas of high salinity and least in areas of low salinity, e.g. the South Fyn Archipelago. Eelgrass has not since recolonised to the same extent in deeper waters, as elevated nutrient levels have decreased water clarity and prevented sufficient light from reaching eelgrass in deeper waters.

Depth distribution of eelgrass before (Ostenfeld, 1908) and now:

Location	1900	1996-98
Great Belt	9.4-10.4 m	6-7 m
Little Belt and the South Fyn Archipelago	7.5-8.5 m	5-6 m
Odense Fjord	5.7-7.5 m	2.5-4 m
Nyborg Fjord (inner)	7.5 m	3.5 m
Holckenhavn Nor	1.3 m	No flowering plants

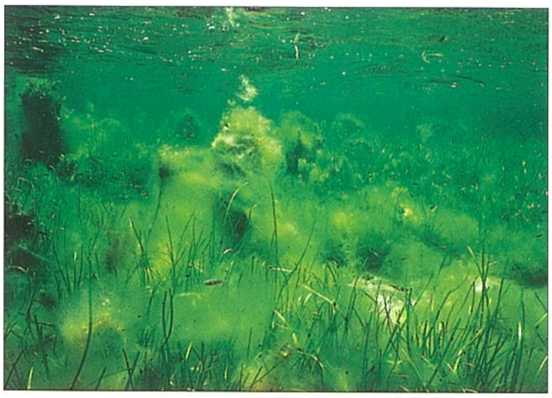


Photo: Nanna Rask, Fyn County Council

Increased growth of filamentous algae has reduced the distribution of eelgrass in the South Fyn Archipelago.

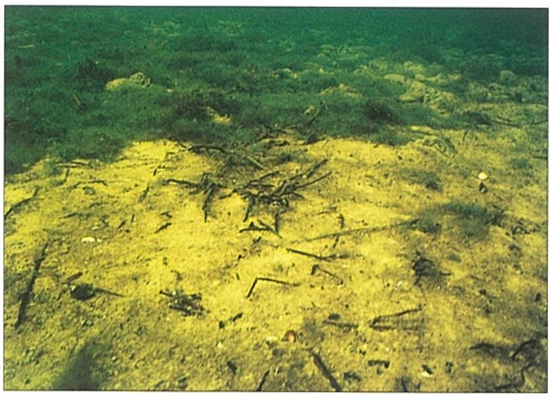


Photo: Nanna Rask, Fyn County Council

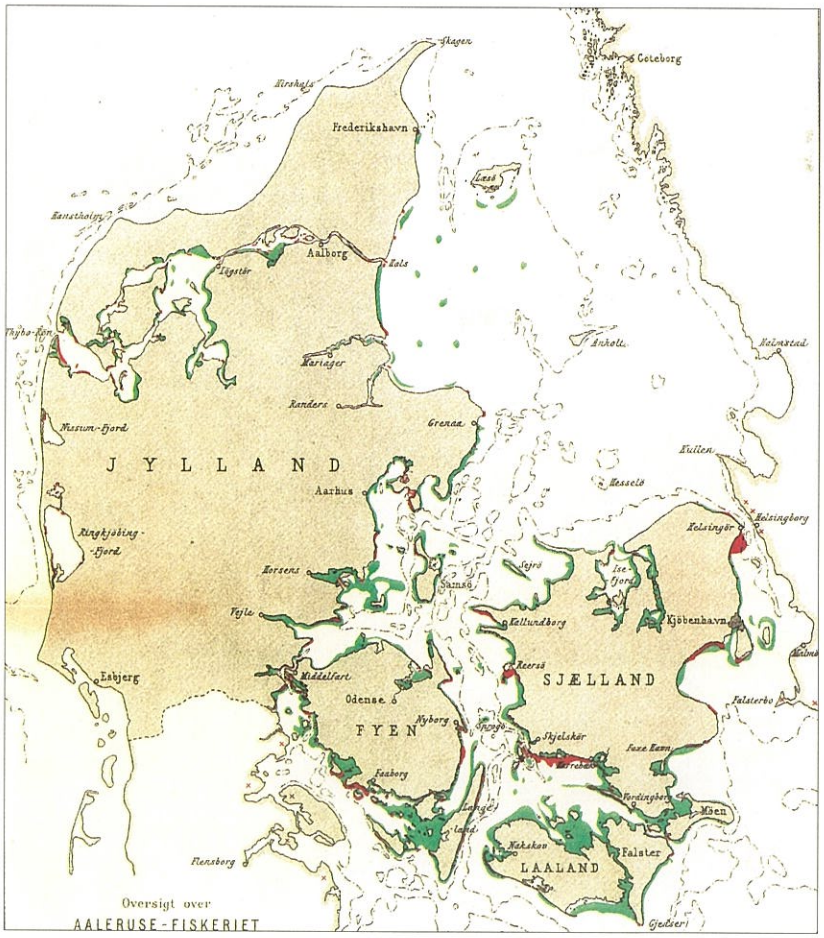
The sea bed in Lindelse Nor in the South Fyn Archipelago where eelgrass previously grew. After a period of oxygen depletion dead eelgrass roots protrude through the surface of the sea bed, and there is an extensive layer of filamentous algae.

al., 2000). The depth distribution of macroalgae has also decreased, from 30-35 m in the Little Belt at the turn of the century (Petersen, 1892) to 10-12 m today. In contrast, quick growing ephemeral algae such as sea lettuce (*Ulva lactuca*) and filamentous species (e.g. *Cladophora* sp.) have increased in abundance considerably, and are now the dominant vegetation in many smaller fjords and coves which receive large loads of nutrients from the surrounding land. In slightly deeper water, particularly in the Little Belt, extensive mats of the purple cyanobacteria *Spirulina subsalsa* often cover both the sea bed and macroalgae.

The large changes in plant communities in Fyn's coastal waters are primarily a result of increases in nutrient loading of coastal waters. High nitrogen concentrations in the water increase phytoplankton growth. As a result, water clarity decreases as does the depth at which macroalgae and eelgrass are able to grow (Sand-Jensen et al., 1994). High nitrogen levels also increase the growth rate of quick-growing ephemeral algae at the expense of eelgrass and the large brown and red algae which are often overgrown and shaded-out by large amounts of quick-growing algae (Borum, 1996). The record-low input of nutrients in 1996 and 1997 allowed partial recovery of the natural vegetation in near-shore waters, such that eelgrass was again found in deeper water - in some locations all the way down to 10 m - and the abundance of sea lettuce was reduced. In the waters to the south of Fyn there was also an increase in the abundance of the eutrophication-sensitive stonewort algae (charophytes). These improvements were, however, not sustained when nutrient loads again increased. Thus, in 1998 and 1999 there was again an increase in the abundance of ephemeral algae in fjords and near-shore waters, while the depth distribution of eelgrass generally fell in 1998 (Markager et al., 1999).

Oxygen depletion in shallow waters can also affect the distribution of eelgrass. Recent studies have shown that low oxygen levels and the presence of hydrogen sulphide in water strongly inhibit the growth of eelgrass, especially in warm summer periods (Greve & Borum, 2000; Holmer & Bondgaard, 2001). Thus, cases of sudden die-off of eelgrass, often seen in late summer, may be partly or solely the result of local oxygen depletion.

Figure 8.10
Distribution of eelgrass (green) and eel traps (red) in Denmark's inner coastal waters in 1899-1900 (Petersen, 1901).



Fish stocks and fisheries in Fyn's coastal waters

Fish are an important element in the aquatic communities in Denmark's coastal waters and, therefore, also in the assessment of the condition of these waters. However, fish are not currently included in the monitoring programme of the Action Plan for the Aquatic Environment.

Until the mid-1990s, fish populations were regularly surveyed by the Danish Institute for Fisheries Research (DIFR). Such activities currently have a low priority in Denmark's inner coastal waters, so fish populations in the waters around Fyn are no longer surveyed, with the exception of investigations of fry in the waters to the north of Fyn.

The descriptions in this section of fish populations in waters around Fyn are based solely on catch statistics from the Danish Directorate of Fisheries and the assessments of fishermen. Catch statistics give only a rough estimate of the size and condition of fish stocks, partly because the size of the catch is dependent on the effort expended, though previous surveys by DIFR have shown a relatively good relationship between numbers of fish caught and size of fish populations (Bagge et al., 1989).

Photo: Nanna Rask, Fyn County Council

*Rainbow trout (*Salmo irideus*) in a net enclosure of Bågø aquaculture facility in the Little Belt.*

Statistics from the Danish Directorate of Fisheries

Fish catches in Fyn's coastal waters for 1978-1998 are described in the catch statistics of the Danish Directorate of Fisheries for the Western Baltic Sea and the Belt Seas (Area 22; Figure 8.11). Catches of cod (*Gadus callarias*), following a period of continuous, rapid fall, have increased considerably since 1994, but have not returned to the level at the beginning of the 1980s (Figure 8.12a).

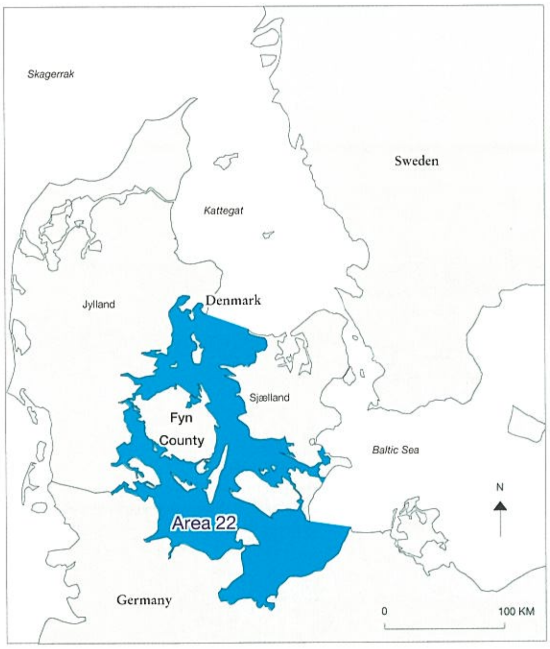


Figure 8.11
Perimeter of Area 22, Western Baltic Sea and Belt Sea, according to the definition of the Ministry of Food, Agriculture and Fisheries.

Catches of plaice (*Pleuronectes platessa*) have also increased considerably since 1994, but remain only at one-third of the level during the 1970s. Turbot (*Scophthalmus maximum*) has constituted a small, but valuable part of fish catches in recent years. After a period of continuous fall, catches of flounder (*Platichtys flesus*) have also increased since 1994, whereas catches of dab (*Limanda limanda*) have fallen (Figure 8.12b).

Table 8.2
*Estimated catches of sea trout (*Salmo trutta*) in Odense Fjord and Gl. Kanal (lower reaches of Odense Å) in 1995 in relation to fishing tackle.*

Fishing tackle	Percentage
Gillnet	43%
Pound net	12%
Angling in fjord	24%
Angling in Gl. Kanal	21%

Catches of yellow and silver eel (*Anguilla anguilla*) have fallen for many years, and are now only one-fifth of the level of 20 years ago (Figure 8.12c).

Fishing industry assessments

Local representatives of the fishing industry are moderately optimistic regarding recent years' developments. There is particular optimism regarding the cod fishery where, in addition to many fish over the minimum length required of 35 cm being caught, many young fish are also being netted. This gives the expectation that the cod fishery will remain sound in coming years.

In contrast, there are no signs of positive developments in the eel fishery. The number of eel fishermen in 1998 was only roughly 15% of the number of 10-20 years ago. Catches of herring (*Clupea harengus*) and sprat (*Clupea sprattus*) in Area 22 have been roughly constant in recent years.

Recreational fishing

Recreational fishing is primarily focussed on a few marine species, notably sea trout, eel, cod, flounder, and turbot, though many other species are caught. There are some 14 800 sports fishermen in Fyn, and 5 000 hobby fishermen, who fish along the coastline with nets and traps.

In Denmark, the sea trout is subject to intensive husbandry and protection, financed by the licence fees paid by both sports- and hobby fishermen. In addition, Fyn County Council, in cooperation with the sports fishermen of Fyn, has since 1990 annually released large numbers of trout smolts as part of an environment and tourism project. Thus there is considerable interest in the sea trout fishery, and to the size of the catches of the different groups of recreational fishermen. Sea trout catches are the subject of additional interest, as the adult fish are present in coastal waters and fjords each autumn on their way towards and up watercourses in order to spawn. If the fishery in coastal waters is too intensive, too few fish may reach their spawning grounds.

DIFR investigated the sea trout fishery in Odense Fjord in 1995, and estimated the total catch to be some 7 100 fish in the fjord and the lower reaches of Odense Å (Odense Gl. Kanal). Only a minor part of the net fishery in Odense Fjord is commercial, the majority being recreational fishing. Roughly half of the sea trout landed were caught in gillnets (Table 8.2).

In comparison, commercial sea trout fishermen around Fyn land roughly 5 000 kg of fish annually. Assuming an average weight of 2.5 kg per fish this represents some 2 500 sea trout. Although these are minimum figures for the commercial fishery, and the results of the afore-mentioned survey of sea trout catches in Odense Fjord may not be representative of Fyn as a whole, it appears that recreational fishermen land considerably more sea trout than the commercial fishery.

Overall assessment of fish stocks

The Belt Sea and Western Baltic Sea have traditionally been important fishing grounds, in particular for species such as cod, various flatfish, herring, and eel. From the 1970s to mid 1980s, catches of most fish species fell considerably. Investigations by DIFR indicate that deteriorating environmental conditions such as more extensive oxygen depletion, changes to and reduced abundance of benthic animal communities, and the presence of ephemeral algae at the expense of eelgrass have combined to reduce the availability of food and nursery grounds for young fish, and to increase the incidence of disease among fish (Bagge et al., 1990; Nielsen, 1997). More intensive fishing, as a result of technological developments, has also contributed to the marked decrease in the size of fish stocks, notably cod.

From the end of the 1980s and beginning of the 1990s catches of cod in particular, to a lesser extent plaice and flounder, have increased. It is difficult to assess reliably the size and condition of fish stocks on the basis of the amounts of fish landed, however the recent years' improved catches, and the optimistic views of the fishing industry regarding conditions in the waters around Fyn, suggest positive developments in the size and health of many species of fish.

Fyn County Council's Regional Plan includes the objectives that all the waters around Fyn should be suitable for fish and recreational and/or commercial fishing, and that waters, where the appropriate natural conditions prevail, are suitable for the reproduction and/or growth of fish. These requirements are in good agreement with the fishing industry's wish of a diversity of fish species. Thus it is desirable that suitable monitoring of fish stocks be undertaken, including both commercially important species and other species present in the waters around Fyn.

Fishing fleet of Fyn County

There are currently some 230 fishing vessels sailing out of harbours around Fyn, which is some 70 less than in 1988. The vessels fish with trawls, nets, and pound nets, and a few are Danish seiners. The majority of vessels are equipped for trawling.

Danish vessels annually catch fish with a value of some 3 000 million Danish kroner (1997 values). Catches in the western Baltic Sea and Belt Sea amount to 400 million kroner, including cod for 109 million kroner, flatfish for 34.9 million kroner, and eel for 1.6 million kroner.

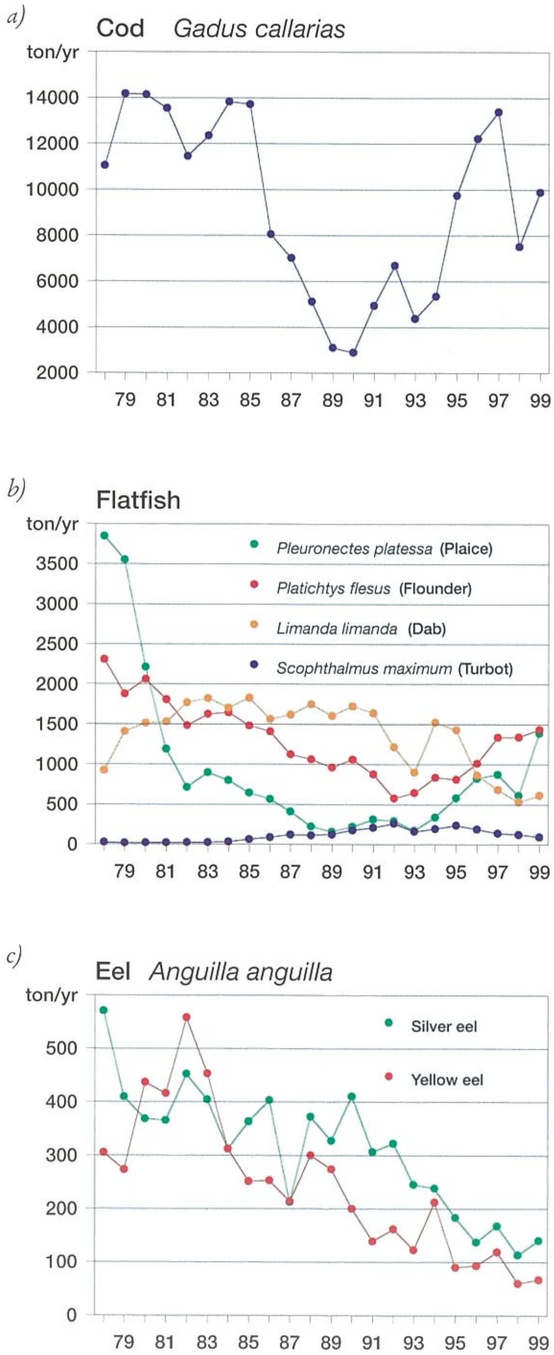


Figure 8.12 Catches (tonnes/yr) of (a) cod; (b) flatfish: divided into plaice, flounder, dab, and turbot; and (c) yellow eel and silver eel in Area 22 during the period 1978-1999.

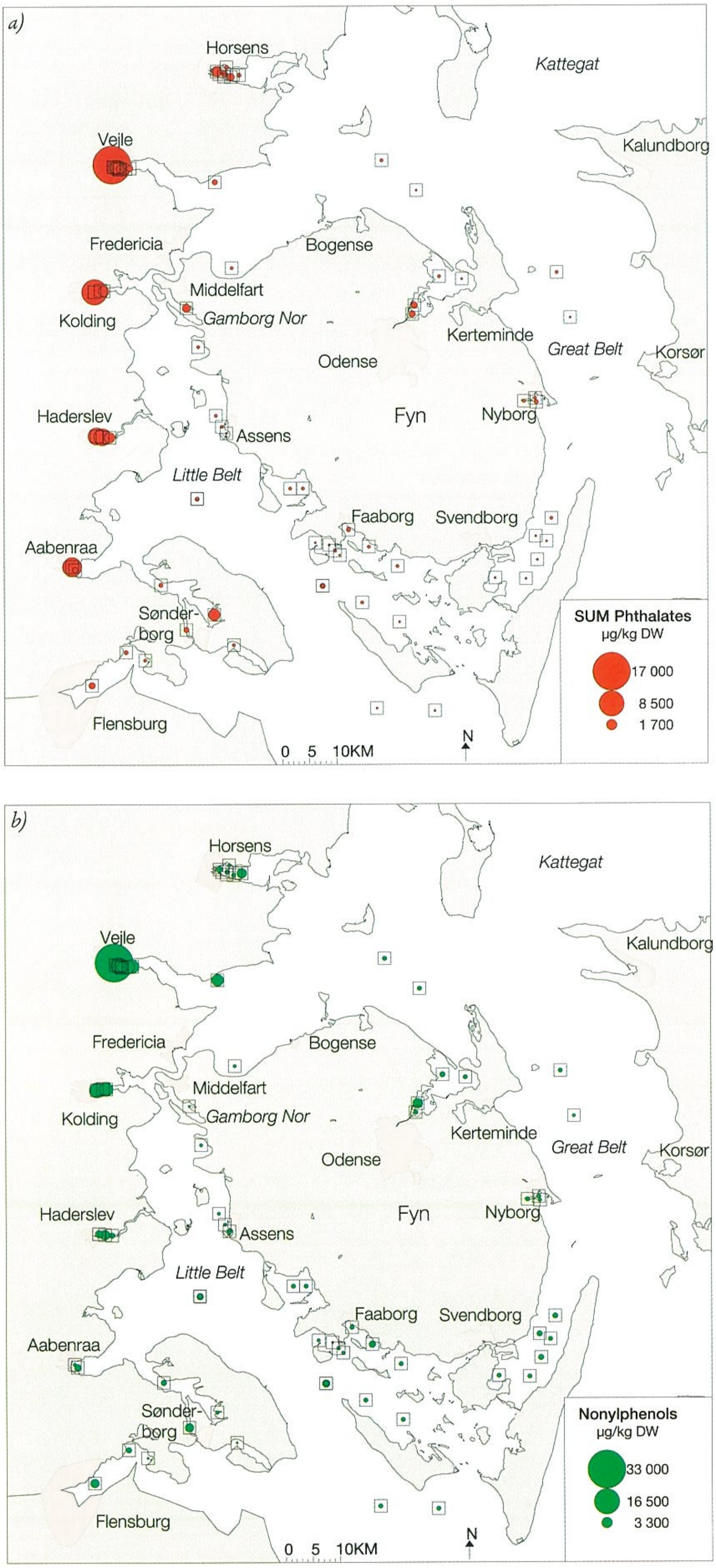


Figure 8.13 (a-c)
Concentrations (µg/kg DW) of (a) phthalates, (b) nonylphenols, and (c) PAHs in sediment samples collected from the coastal waters around the counties of Fyn, Sønderjylland and Vejle.

Hazardous substances

In 1997, the County Councils of Fyn, Sønderjylland, and Vejle collaborated in an investigation of the presence of hazardous substances (i.e. substances that are toxic, persistent and liable to bio-accumulate) in the marine environment common to the three counties (Lillebæltsamarbejdet, 1998).

Sediment samples were collected from 66 stations in the coastal waters around the three counties. The samples were analysed for 110 organic pollutants from the following categories: phthalates, nonylphenols, p-triesters, chlorobenzenes, phenols, PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls), LAS (linear alkylbenzene sulphonate), and pesticides.

Occurrence

Chemicals from all the categories were found in sediment samples from the coastal waters around the three counties (Table 8.3). Highest concentrations were found in sediments from the upper reaches of fjords in Jylland and Fyn, at locations where watercourses or point-sources discharge to the marine environment, and in smaller, enclosed coves such as Gamborg Nor in Fyn County. The concentrations of chemicals in sediments decrease when mowing towards open waters.

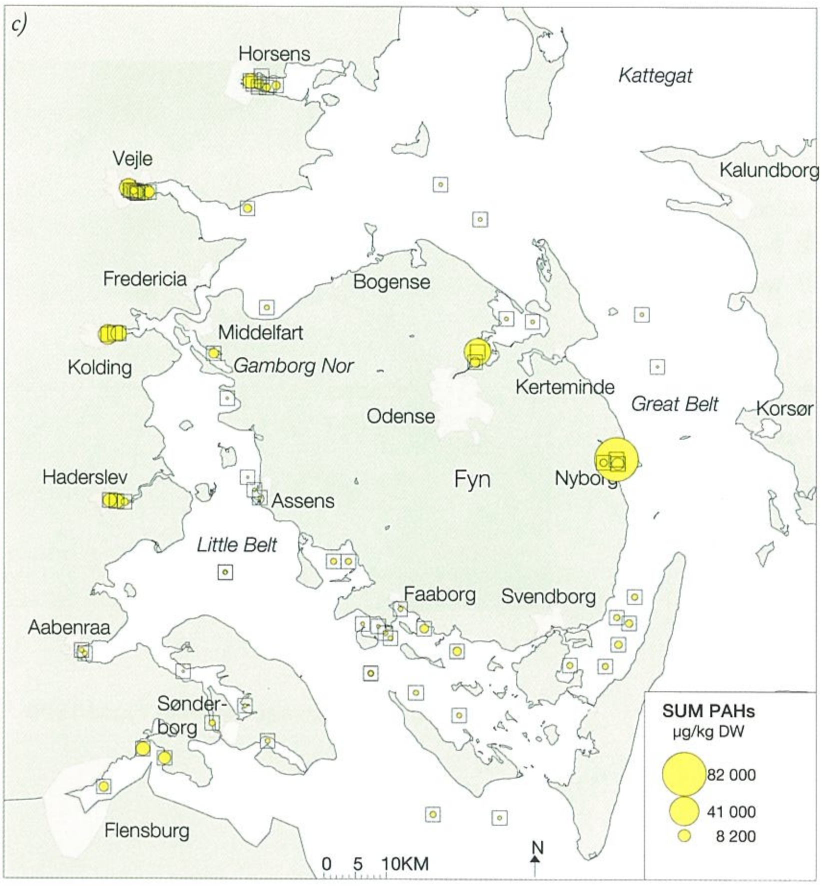
Phthalates, nonylphenols, and PAHs, which are toxic to aquatic organisms, were found at all 66 stations (Figure 8.13a-c).

Pesticides were found at 25 of the 66 stations, primarily those in fjords and coves. The previously used, but now prohibited, PCBs and chlorinated pesticides (DDT, DDD, and DDE) were only found in Vejle Fjord and Kolding Fjord. The prohibited insecticides heptachlor, aldrin, dieldrin, and endrin were also present in relatively high concentrations at these locations.

Phenols were only found in sediments around Fyn, and were present at particularly high concentrations in the upper reaches of Odense Fjord. LAS, used in cleaning and washing agents, was found at 24 of the 66 stations. P-triesters and chlorobenzenes were present in low concentrations at roughly 20% of the 66 stations.

Ecological risk assessment

The concentrations of these organic contaminants in the sediment have been assessed in relation to a range of ecotoxicological sediment criteria endorsed by the Oslo-Paris Convention (OSPARCOM) and to guidelines otherwise recommended (Long et al., 1997; Burton, 1992). According to these assessment criteria PAH concen-



Hazardous substances

Hazardous substances are chemicals that are toxic, persistent and liable to bio-accumulate and generally do not occur naturally in the environment. The production of chemicals has increased dramatically over the last 100 years. Production of organic compounds has increased from about 1 million tonnes in 1930 to more than 300 million tonnes in 1990. Some 20 000 different chemicals are in regular use in Denmark. They are used by industry, agriculture, and in domestic situations, and are used in construction, plastics, surface coatings, medicines, cosmetics, foodstuffs, pesticides, and many other products and activities. Hazardous substances are harmful to and can cause reproductive disorders in plants, animals, and humans.

trations at more than half the stations represent a probable-effect range within which effects would frequently occur. In both Nyborg and Odense Fjord the levels are 10-15 times the concentration at which effects can be expected. Likewise, PCB concentrations in the upper reaches of Vejle, Kolding, and Flensborg Fjords are at levels at which harmful biological effects can be expected. Concentrations of the pesticides DDE and dieldrin in the upper reaches of Vejle Fjord and Kolding Fjord are up to 200 times the levels known to affect aquatic animals. Phthalate concentrations in the upper reaches of Vejle Fjord also exceed American values above which effects on aquatic organisms can be expected. Phenol concentrations in sediments in the upper reaches of Odense Fjord exceed sediment decontamination standards.

Thus, investigations of marine sediments in the counties of Fyn, Sønderjylland, and Vejle show that various hazardous substances have accumulated to concentrations where harmful effects on marine vegetation and animals can be expected.

Type of substance	All stations examined, n=66			Application/origin
	Number of stations with finds	Max. concentration µg/kg DW	Mean concentration µg/kg DW	
Phthalates	66	16 911	1 035	Plastics, paint, glue, etc.
Nonylphenols	66	33 000	1 877	Cosmetics, varnish, paint, washing and cleaning agents
P-triesters	12	220	65	Plastics, lubricants, flame retardants, etc.
Chlorobenzenes	14	74	16	Production of pesticides and colour pigments
Phenols	14	1 116	130	Various industrial uses
PAHs	66	81 620	5 744	Incomplete combustion, oil-spills, specific industrial processes
LAS	24	22 000	1 875	Washing and cleaning agents
PCBs	3	140	77	Condensers and transformers, plasticizing agents
Pesticides	23	3 721	647	Farming, forestry, horticulture, private gardens, etc.

Table 8.3
Prevalence of the selected hazardous substances in sediments. The number of stations at which the substances occurred and the maximum and mean concentrations are given. Mean concentrations are calculated for the number of stations at which the substances occurred (column 1), not for the total number of stations examined.

Figure 8.14
Monitoring stations for hazardous substances in Odense Fjord.

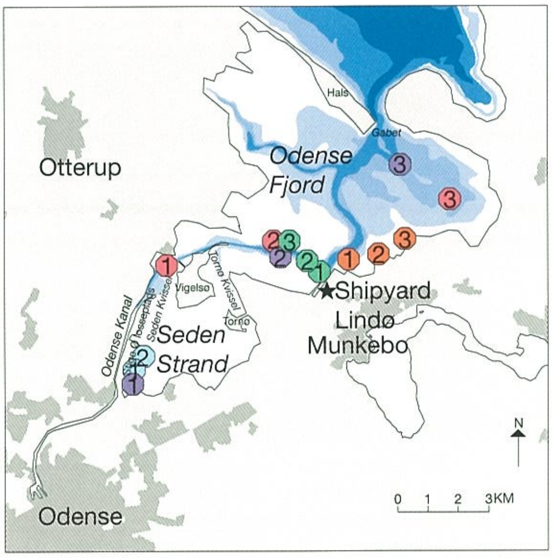


Figure 8.15
TBT concentrations in common mussels in Odense Fjord in 1999. Values are mean ± standard deviation. The horizontal line indicates the upper limit for effect (OSPARCOM). A concentration above the upper limit represent a probable-effect range within which effects would frequently occur.

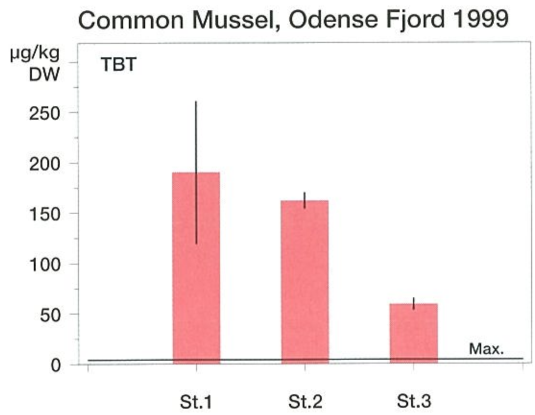
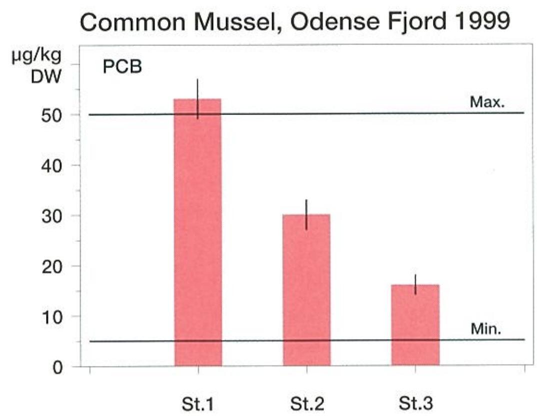


Figure 8.16
PCB concentrations in common mussels in Odense Fjord in 1999. Values are mean ± standard deviation. The horizontal lines indicates the effect interval (OSPARCOM). A concentration below the lower limit represents a minimal-effects range, while a concentration in the interval represents a possible-effects range within which effects would occasionally occur. A concentration above the upper limit represents a probable-effects range within which effects would frequently occur.



Hazardous substances in Odense Fjord

In the marine monitoring programme, NOVA 2003, organic contaminants and heavy metals are monitored at 17 locations around Denmark. Odense Fjord is one of six locations that are surveyed particularly intensively. The presence of these substances is investigated in sediments (data not presently available), in the water and in common mussels (*Mytilus edulis*). Additional investigations include the prevalence of malformations in the genital system of periwinkles *(Littorina littorea)*, caused by exposure to certain organic contaminants.

Seawater

Seawater samples from two stations have, on a single occasion, been analysed for the presence of halogenated aliphatic hydrocarbons, PCP (pentachlorophenol), and LAS (linear alkylbenzene sulphonates). Only LAS was present at concentrations above the detection limit, but at a concentration assessed to be non-harmful to animals.

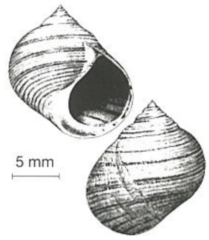
Mussels

Common mussels from three stations (Figure 8.14) are monitored annually for organotin, PCBs, and PAHs, and the pesticides lindane and DDT. All these pollutants have been found in the mussels. Tributyltin (TBT) and PCBs were in concentration ranges within which effects would frequently occur for TBT and occasionally occur for PCBs. Thus, concentrations of TBT were 70 times higher than the ecotoxicological criteria endorsed by the Oslo-Paris Commission (OSPARCOM), while PCB concentrations represent a possible effect-range (Figure 8.15 and 8.16). This is also the case for the concentrations of a single PAH. The other contaminants found in the mussels do not exceed concentrations expected to be harmful.

Common mussels. Photo: Nanna Rask, Fyn County Council

Odense Canal.

Photo: Nils Daell Kristensen, Fyn County Council



Periwinkles.

Snails

Common periwinkles, *Littorina littorea*, are examined annually for malformation of their genital system. Snails are collected from three stations at distances of 25 m to 3 km from potential sources of organotin pollution (Figure 8.14).

Common periwinkles develop malformations of their genital system caused by TBT. The intensity of the phenomenon is correlated with the degree of contamination in the environment. The malformations affect their ability to reproduce.

In female snails, the malformations are manifest as the development of male sexual characteristics (intersex), which can make them sterile. In males, a reduction in the number of mamilliform penial glands occurs. In highly contaminated areas, many male periwinkles do not exhibit any mamilliform penial glands, and it is believed that these specimens are no longer capable of successful breeding.

Malformations have been observed in up to 57% of female snails at the station closest to the source of the TBT discharge, and in 13% of female snails at the station furthest away (Figure 8.17). In males, the degree of malformation is also greatest at the stations closest to the TBT source (Figure 8.18).

Release of TBT from ships is the primary source of TBT entering the marine environment. TBT is used as an antifouling paint, preventing plants and animals growing on the hulls of ships and reducing their sailing speed. Its use is prohibited on boats of less than 25 m in length, though TBT can still be used on larger vessels. The Lindø Shipyard and traffic in the shipping lanes are the major sources of TBT in Odense Fjord.

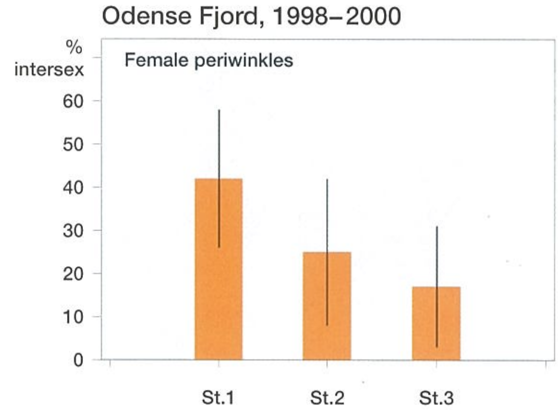


Figure 8.17
Frequency (%) of female common periwinkles with malformations (intersex) in Odense Fjord during the period 1998-2000. Values are mean ± standard deviation.

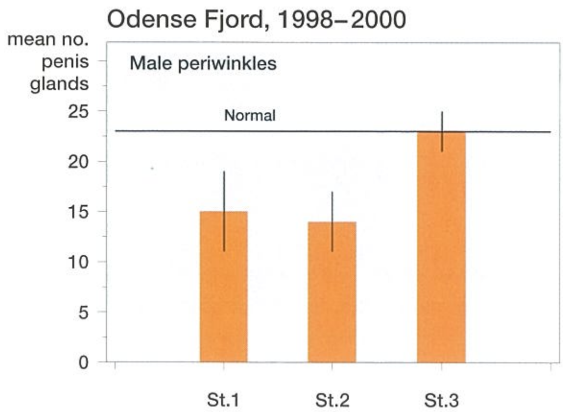


Figure 8.18
Average number of mamilliform penial glands of male periwinkles in Odense Fjord during the period 1998-2000. Values are mean ± standard deviation. The horizontal line indicates the lower normal number of glands in male periwinkles.

Bathing water quality

The 1 100 km of coastline around Fyn County offers many opportunities for leisure activities such as sailing, hobby- and sports fishing, windsurfing, and last, but not least, bathing. It is important for all users that Fyn's coastal waters are clean, clear, and inviting. For bathers it is especially important that the water does not contain large numbers of pathogenic bacteria. Sources of bacteria entering coastal waters include wastewater, stormwater overflows, and discharges from scattered homes. Such emissions may occur directly to coastal waters or via watercourses. Effective waste water treatment removes the majority of bacteria, though only with specialised and relatively expensive methods is it possible to reduce the number of bacteria in treated wastewater to below the requirements for bathing waters. As faecal bacteria live for a longer time in freshwater, bathing in watercourses receiving wastewater is not advised. In salt water, faecal bacteria typically die after a few days. Thus, effective wastewater treatment, combined with dilution and dispersion of wastewater far from the coastline via long sea outfalls, can minimise the risk of coastal locations with poor bathing water quality.

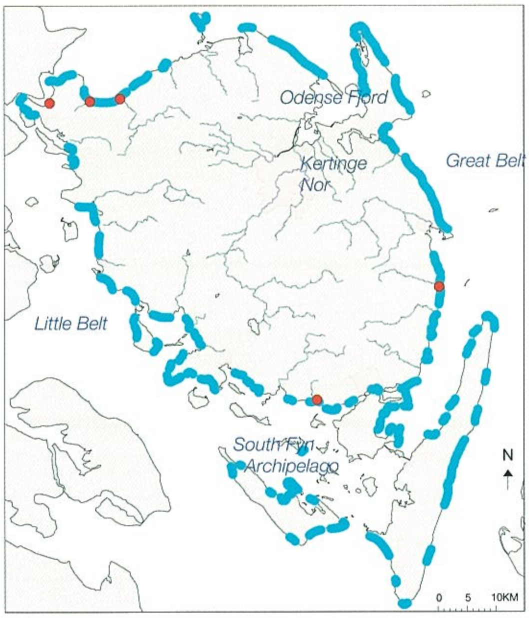


Figure 8.19
Bathing water map for Fyn County for 2000. The blue zones show where bathing water quality requirements have been met, and the red circles locations where bathing is prohibited.

- Bathing not permitted in 2000
- Bathing areas

Regulations

Regulations governing the inspection of Danish bathing waters are drafted by the Danish Environmental Protection Agency (DEPA) and are in compliance with EC regulations for bathing waters. Inspection is performed by municipalities, often with the assistance of an analytical laboratory, which collects samples of bathing water, makes an on-site assessment, and determines numbers of colibacteria in samples. Samples are collected on a regular basis between May and October at locations distributed around the majority of the County's coastline (Figure 8.19).

Danish regulations for the hygiene of bathing waters set an upper limit of 1 000 faecal coli bacteria per 100 ml of water. In bathing water this limit must be met for at least 95% of the bathing season. Compliance is determined on a statistical basis according to a method recommended by the DEPA, which is based on the number of samples and the variation in the numbers of coli bacteria present.

Assessment and presentation of data

Local authorities forward their results to Fyn County Council and the Medical Officer of Public Health, who together assess the hygienic water quality during the season for all bathing locations in the County. After discussion with the Medical Officer of Public Health, the County authorities send comments to the individual municipalities regarding, for example, the number of samples that should be collected in the coming season and, in some cases, more extensive sampling or bathing restrictions.

Coli bacteria

The term faecal coli bacteria is a synonym for heat-tolerant coliform bacteria, a collective description for a group of bacteria that live in the intestines of warm-blooded animals, including humans. Faecal coli bacteria are primarily represented by *Escherichia coli*, which does not generally cause sickness, though the group does include a number of other species. The total number of coli bacteria in bathing waters is often given as the number *E. coli*, even though this is slightly misleading.

Faecal coli bacteria have been selected as an indicator organism, as they are always present when pathogenic bacteria are present. They are also present in large numbers and survive to the same extent as pathogenic bacteria in the aquatic environment.

Bathing restrictions

Bathing restrictions are generally introduced at a location if the requirements for water hygiene are not met for three successive seasons. In addition, the presence on a single occasion, of large numbers of *E. coli* can result in bathing restrictions if the sources of the bacteria cannot be traced and the problem rectified. Bathing restrictions can also be brought into force mid-season if unacceptable water hygiene arises that cannot be abated and which appears to pose a risk to the health of bathers. Blooms of toxic algae can also result in the introduction of bathing restrictions. Bathing restrictions can first be lifted when the contamination responsible has been brought under control.

Each year, Fyn County Council produces a bathing water map which shows the areas of the coastline inspected and the primary bathing beaches. The map also shows any locations where the hygiene requirements for water quality were exceeded the previous year, and the location of bathing restrictions in the current year. The map is also available at www.fyns-amt.dk\badevand.

Parallel to the County Council's bathing waters map, DEPA issues an equivalent map for the whole of Denmark, and the European Commission a map which covers all EC countries.

Conditions and developments

In 1999, 2 339 water samples were collected from 210 stations around Fyn County's coastline.

In 1999, as in other years, the quality of the bathing waters around Fyn was good. There has been a considerable improvement in water quality over the last two decades (Figure 8.20). In 1982, 95% of samples contained less than roughly 900 coli bacteria per 100 ml of water, whereas in 1999 the figure was less than about 250 coli bacteria per 100 ml. This improvement is the result of considerable efforts to reduce waste water loading of coastal waters and watercourses.

Prohibition of bathing

There remain locations where water quality has not yet reached the required level, mainly at the mouths of watercourses entering bathing waters.

The recurrent problem with water quality at the mouths of watercourses is primarily the result of discharges from scattered homes around the watercourse. The County Council's Regional Plan has, for selected areas, established guidelines for improving wastewater treatment in rural areas. These improvements are required to be made before the end of 2005, and are expected to improve the hygienic water quality in selected watercourses.

For health reasons it is generally not recommended to bathe near the mouths of watercourses.

Blue Flag

In addition to the compulsory inspection of bathing waters, selected locations are also inspected according to the EC's Blue Flag criteria. This involves analysis for faecal streptococcus bacteria in addition to faecal coli bacteria. Further requirements for the issue of a Blue Flag include certain beach-side facilities such as toilets and car parking. In Denmark, the Danish Outdoor Council is responsible for issuing of Blue Flags.

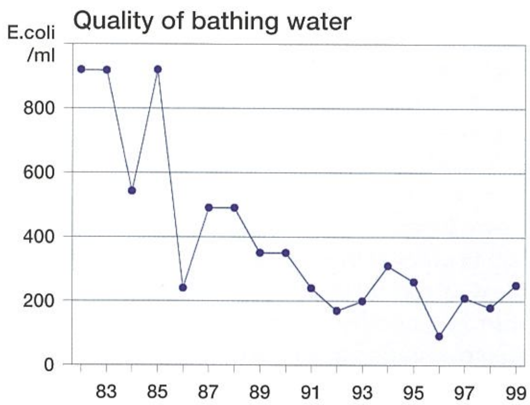


Figure 8.20
Trends in bathing water quality during the period 1982-99 for all the County's bathing water sampling stations, expressed as the 95% quantile of all E. coli *measurements for each year.*

The beach at Kerteminde. *Photo: Nils Daell Kristensen, Fyn County Council*

Effects of wastewater treatment

In fjords and coastal areas near the mouths of rivers and wastewater outlets, improved collection and treatment of wastewater at industrial and municipal wastewater facilities have resulted in large reductions in loading with phosphorus in particular. Reduced loadings have resulted in lower winter concentrations of phosphorus at locations such as Snævringen in the Little Belt, Svendborg Sund, and Odense Fjord (Figure 8.21). In many areas, notably those with a relatively small catchment, reduced input of nutrients has resulted in improvements in the aquatic environment: algal abundance has decreased, visibility has increased, and oxygen conditions improved. In shallow areas, such as Odense Fjord, the abundance of ephemeral algae such as sea lettuce has declined, while the perennial seagrasses and eelgrass have become more abundant.

Previous years' discharges of wastewater have, however, resulted in the accumulation of large amounts of nutrients in the sediments of the sea bed, particularly in more enclosed areas where sludge has accumulated on the sea floor, e.g. in Helnæs Bugt and Kertinge Nor. In the warm, calm summers of 1994, 1997, and 1999 unusually high water temperatures in shallow, coastal areas resulted in the release of large amounts of nutrients to the water. As a consequence, algal blooms developed in many areas during the late summer, and poor oxygen conditions developed at many locations, e.g. in Kertinge Nor. Thus, the full benefits of improved wastewater treatment in local, more enclosed coastal waters will first be seen in a number of years, as the amount of nutrients accumulated in the sea bed declines.

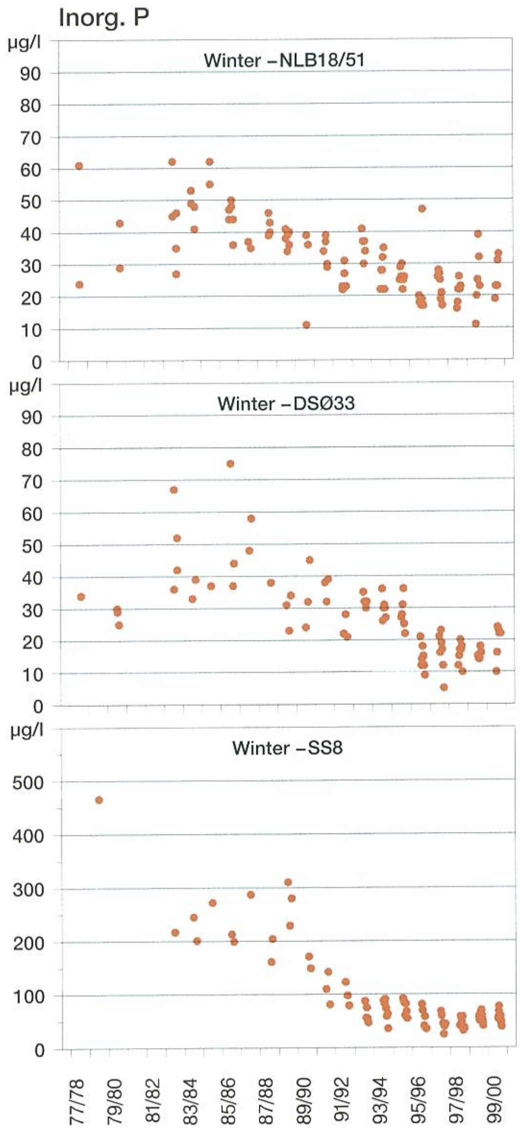


Figure 8.21
Winter (Dec.-Feb.) concentrations of inorganic phosphorus in Snævringen in the northern Little Belt (stations NLB51 and NLB18), in Svendborg Sund (DSØ33), and at Seden Strand in the inner part of Odense Fjord (SS8) during 1977/78-1999/00.

Photo: Nanna Rask, Fyn County Council

Many fjords, coves, and inlets around Fyn County have previously been heavily impacted by discharges of wastewater. The flora and fauna have declined, and perennial seagrass and eelgrass have been overgrown by small, rapidly growing algae, such as here at Nærå Strand in 1987.

Photo: Nanna Rask, Fyn County Council

The natural vegetation of the shallow waters around Fyn is a varied community of eelgrass, seagrass, stonewort algae, and broad-fronded red and brown macroalgae, such as shown here in an area of the South Fyn Archipelago relatively unimpacted by nutrients.

Cleaner coastal waters - how ?

Fyn County Council's Regional Plan 1997-2009 sets out objectives for environmental conditions in the County's coastal waters. Most areas are encompassed by the basic objective that they should be "suitable for fish and for recreational and/or commercial fishing, and allow the reproduction and growth of fish, where the appropriate natural conditions prevail". A number of areas considered important natural environments have been identified and designated "Scientific Reference Areas", and are required to meet more demanding water quality objectives (Figure 8.22).

Surveillance data for 1996-1997, when record-low amounts of nitrogen and phosphorus entered Fyn's coastal waters, so fulfilling for the first time the reduction targets of the Action Plan for the Aquatic Environment (APAE), showed a rapid improvement in conditions in the aquatic environment. However, the marked improvements did not last in 1998 and 1999, when runoff of nitrogen especially again increased as a result of higher levels of precipitation. Thus, in the summers of 1998, 1999, and 2000 poor oxygen conditions were registered in all major coastal areas, and in 1999 sizable blooms of toxic algae also occurred during the summer.

The objectives for Fyn's coastal waters have, therefore, not yet been met. Lasting improvements in the condition of coastal waters are dependent on further reductions in emissions of nitrogen and phosphorus. To begin with, total emissions of nutrients from Fyn need to be permanently reduced to at least the minimum requirements of a 50% reduction for nitrogen and an 80% reduction for phosphorus, as set out in the APAE I and II.

Measures taken with respect to wastewater treatment have ensured that these objectives have been met by urban areas and industries since 1991/92. In certain coastal areas and fjords these efforts have already resulted in considerable improvements in the environment. Meeting the water quality requirements for the coastal waters, fjords, and inlets around Fyn in genereal, however, will first be possible when agriculture has met the reduced emission requirements of the APAE I and II. In particularly sensitive areas, e.g. parts of the South Fyn Archipelago, additional reductions will be necessary. In these particularly sensitive areas, municipal wastewater treatment will need to be performed to higher standards than those set out in the APAE I and II (see Chapter 5).

Recent studies have shown that in addition to the well-known leaching of nitrogen from agricultural land, phosphorus is also being leached directly from farmed land to an increasing extent (Nielsen, 1998). Nature rehabilitation by reestablishment of wetlands and adherence to laws regarding cultivation-free zones adjacent to watercourses will help to retain nutrients - both nitrogen and phosphorus - washed from agricultural land. Establishment of water meadows in the catchments of fjords and coves, as stipulated in the APAE II, will also reduce leaching of nutrients. These measures can reduce loading of the aquatic environments at both a local and regional level.

In many shallow-water areas, dams and dikes have reduced water circulation. At such locations it may be necessary to increase water exchange in order to achieve water quality objectives.

In addition, it is also important to address sources contributing to atmospheric deposition of nutrients. During the summer, and in dry years, when loading from land is relatively small, atmospheric deposition can be a significant source of nutrient input to open coastal waters relative to runoff from land.

Last, but not least, it is also important to limit discharges of hazardous substances to the marine environment.

Action plans

For surface water, as decided for groundwater (see Chapter 2 and Chapter 9), it would be appropriate to draft action plans for particularly sensitive waterbodies and their catchment areas. Such action plans should describe the acceptable loading for an area in relation to the desired objectives for that area. The entire catchment area feeding a water body should be included when describing pollution control measures for agriculture, industry, and households, and all relevant pollutants - both nutrients and hazardous substances - should be considered (Petersen, 1999).

These efforts will also be in accordance with the future requirements set by the EC Water Framework Directive, where each country shall produce river basin management plans for each river basin district before 2009.

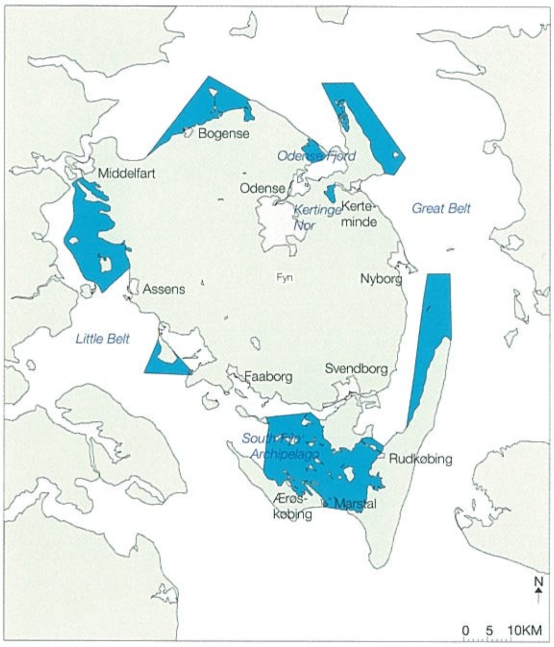


Figure 8.22
Water quality objectives in Fyn County Council's Regional Plan 1997-2009. The designated "Scientific Reference Areas" (dark blue), are required to meet more demanding water quality objectives.

Reference sites for scientific studies

Artesian well. Photo: Bert Wiklund

9 Groundwater

Tomorrows groundwater is formed by today's precipitation. New groundwater is not, however, formed every time it rains. During the summer all rainfall is either taken up by plants, evaporates from the ground, or, to a limited extent, runs off the land to watercourses. Only excess precipitation during the winter period from October to April becomes new groundwater.

As water percolates through the ground it is naturally filtered and cleansed by bacteria and by the exchange of substances with various layers of soil. It normally takes many years for precipitation to become groundwater. Groundwater close to the ground surface can be 10 years old, while deeper groundwater can be considerably older.

In past centuries, the majority of drinking water came from thousands of wells in towns and the countryside. As towns developed and grew the need to establish proper waterworks arose. The first waterworks in Fyn County were built some 150 years ago. Today, abstraction of groundwater to supply drinking water is carried out at 272 waterworks with a total of approx. 860 boreholes spread throughout the County. In addition, drinking water is abstracted from some 7 000 - 8 000 wells and boreholes, primarily on private properties in rural areas.

Geological formation of the landscape influences the possibilities for abstraction of water. In some regions water quality is poor, due to the geology. In other regions the groundwater is sensitive to contamination, as it lacks protection in the form of thick layers of overlying clay.

Fyn County monitors trends in the quality and utilisation of groundwater. This is carried out partly by determining the concentrations of nutrients and other substances, both naturally occurring and hazardous substances (i.e. substances that are toxic, persistent and liable to bio-accumulate) in groundwater. This monitoring is based on data collected by waterworks in connection with control of drinking water and groundwater, and data collected by the County in six selected surveillance areas as part of the national monitoring programme, NOVA 2003.

Groundwater resources

The amount of groundwater

In its Regional Plan 1997-2009, Fyn County Council prioritised groundwater resources by dividing the County into regions with major drinking water interests, regions with drinking water interests, and regions with limited drinking water interests (Figure 9.1). Protection of the regions with major drinking water interests will ensure, with a reasonable margin of safety, the availability of sufficient amounts of uncontaminated drinking water now and in the future.

The total volume of groundwater formed annually in Fyn County is estimated to 176 million m³/yr. However, only a small part of the total resource can be utilised if consideration is to be given to climatic variation, groundwater quality, and environmental conditions in streams, fens, meadows, etc.

During the last 20 years a relatively large amount of precipitation has fallen compared with the first half of the 1900s. There is thus a risk that long-term groundwater resources may be overestimated if measurements from the last 20 years only are used in calculations, as periods of low precipitation are expected to occur again in the future. To compensate for this, the Danish Environmental Protection Agency recommends that when calculating groundwater resources, the value for the volume of groundwater formed annually should be multiplied by a factor of 0.7. On this basis, the so-called climate-corrected production of groundwater in Fyn County is estimated to 123 million m³/yr.

If watercourses and wetlands are to be maintained in agreement with objectives in the County Council's Regional Plan, the amount of the climate-corrected groundwater production that can be utilised is further reduced. Agricultural pollution, in the form of nutrients and pesticides, and pollution from contaminated industrial sites, old waste dumps and similar sources of contamination, also mean that the portion of groundwater that can be utilised is reduced still further. The so-called wetland-sustaining groundwater resource in the County is calculated to be 65 - 85 million m³/yr.

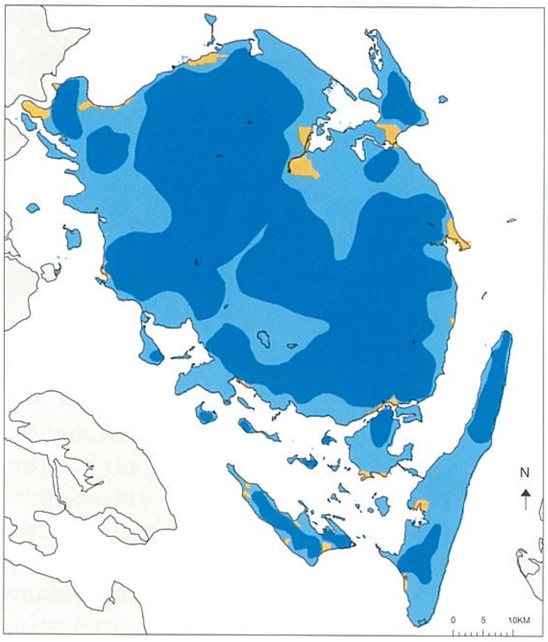


Figure 9.1
Importance of various regions for the supply of drinking water in Fyn County.

Drinking water resources
- of special interest
- of general interest
- of restricted interest

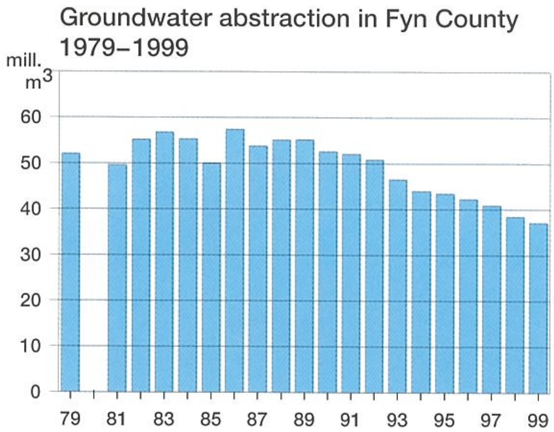


Figure 9.2
Volume of groundwater abstracted annually by waterworks in Fyn County during the period 1979-1999.

A prerequisite to this calculation is that current abstraction activities remain unchanged. If it becomes necessary to close the large, coastal abstraction sites due, for example, to pollution or the infiltration of salt water, groundwater abstraction will be required to move further inland. This will increase effects on the upper reaches of watercourses, where the volume of stream flow is small. Consequently, it may become difficult to maintain quality objectives in watercourses.

Categories of abstractor	Surface water million m³	Groundwater million m³	Total million m³
Waterworks	0.0	37.5	37.5
Individual facilities (industries etc.)	1.7	1.8	3.5
Irrigation, agriculture, horticulture	0.3	3.3	3.6
Properties with own well (estimate)	0.0	3.7	3.7
Total	2.0	46.3	48.3

Table 9.1
Volumes of water abstracted from surface water and groundwater by various groups of abstractors.

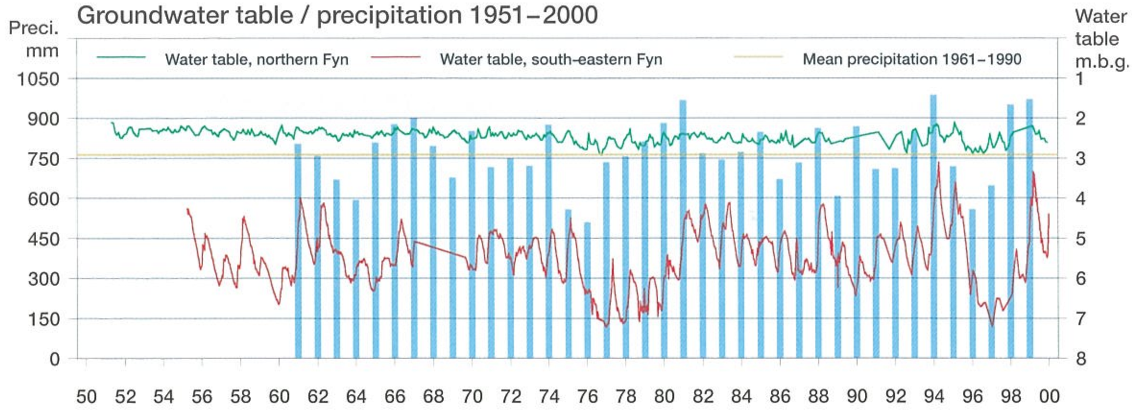


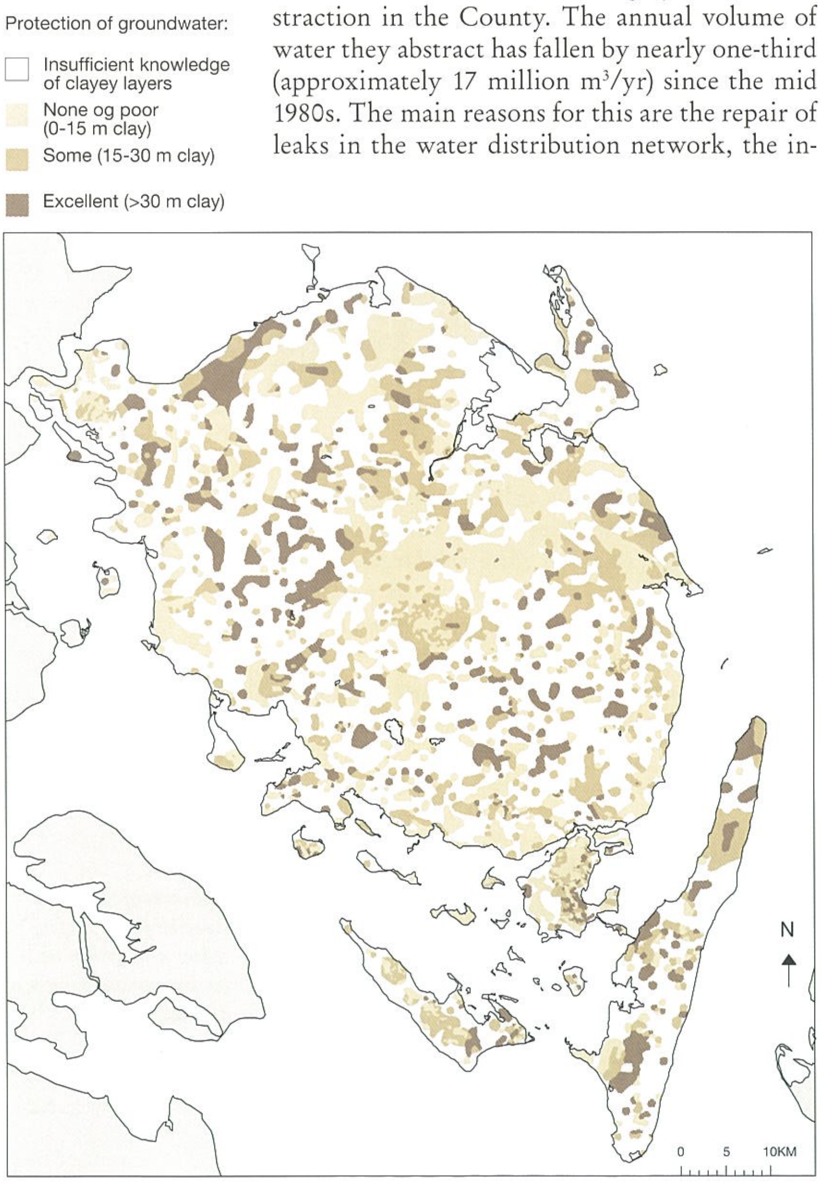
Figure 9.3 Variation in groundwater levels in a regional aquifer in northern Fyn and in a local aquifer (Vejstrup) in south-eastern Fyn, and mean annual precipitation in Fyn County (m.b.g. = metres below ground level).

Abstraction of water

Abstraction of water in Fyn County, as in the rest of Denmark, is based mainly on groundwater (Table 9.1). Less than 5% of the total volume of water abstracted is surface water, originating from larger watercourses.

Waterworks account for roughly 80% of abstraction in the County. The annual volume of water they abstract has fallen by nearly one-third (approximately 17 million m^3/yr) since the mid 1980s. The main reasons for this are the repair of leaks in the water distribution network, the introduction of water metering, and reduced consumption due to increased taxation on drinking water.

Figure 9.4 Prevalence of protective clay layers above groundwater in Fyn County.



Groundwater levels

Abstraction of groundwater results in lowering of groundwater levels. The magnitude of the lowering depends on how much water is abstracted, and the volume of water in the aquifer. The abstraction of a large volume of water from a small aquifer typically causes the groundwater level to drop considerably, as the rate of abstraction is greater than the rate of induced infiltration.

The groundwater level is, naturally, also dependent of the amount of precipitation. In Fyn County this varies locally, the most precipitation falling on central Fyn, and the least along the coastline. The amount of precipitation also varies annually (Figure 9.3; see also Chapter 4). The low amount of precipitation during the years 1995-1997 resulted in less groundwater being formed. For example, in the little, local aquifer at Vejstrup in south-eastern Fyn, the groundwater level dropped by up to 4 m (Figure 9.3). This considerable lowering meant that the groundwater level at the end of 1997 was comparable with that at the end of 1977, a year that was also preceded by several dry years. Large amounts of precipitation during recent winters have caused the groundwater level to return to normal, as was also the case in the period after 1977.

In contrast, climatic variation has only a limited effect on the groundwater level in the large, regional aquifer on northern Fyn. The very dry years at the end of the 1970s and in the mid 1990s caused the groundwater level to drop by only 0.1 - 0.2 m (Figure 9.3).

Groundwater modelling

In order to better calculate the size of available groundwater resources, exchange between surface water and groundwater, and the influence of abstraction on the water cycle, hydrologic mod-

Degree of groundwater protection	Thickness of clay above aquifer (m)	Area of Fyn covered (%)
No or partial protection	0 - 15	22
Partial protection	15 - 30	18
Good protection	> 30	10
Insufficient geological information	?	50

Table 9.2
Degree of natural protection of groundwater in Fyn County.

els have been developed for selected areas in Fyn County.

The largest models cover the river, Odense Å (including a number of the adjacent water systems), and the whole of Fyn. The model for the catchment of Odense Å (1 052 km^2) was developed by Fyn County and Odense Waterworks. The model for Fyn (roughly 3 000 km^2) was developed by the Geological Survey of Denmark and Greenland in 1996-1997. It is the first step towards a National Water Resource Model that will cover the whole of Denmark. The Fyn model has been used to simulate the water balance for the whole County during the period 1989-1996 (see Chapter 4).

The hydrological model for Fyn was developed on the basis of geological information from some 22 000 boreholes and other geological surveys, and incorporates geological profiles, specific geological layers, and their thicknesses.

Groundwater vulnerability and quality

Groundwater quality is largely dependent on geological and hydro-geological conditions.

Overlying clay layers have a considerable influence on the physical, chemical, and biological properties of aquifers because of their capacity to retain or degrade contaminants. The characteristics of geological layers are thus important with regard to the extent to which contaminants can be transported from the ground surface to aquifers.

In connection with the identification of regions with major drinking water resources, surveys were made to determine the total thickness of clay above aquifers throughout Fyn County (Figure 9.4 and Table 9.2).

Groundwater quality, and thus the quality of drinking water, is generally good in Fyn County. However, at many locations the composition of groundwater has been altered by natural conditions or as a result of human activities. The use of fertilisers in agriculture; agricultural, public, and private use of pesticides; deposition of waste from industry and households; geological conditions; and the actual abstraction of water all affect the quality of groundwater. The major problems, examined below, are linked to substances such as nitrate, sulphate, chloride, and various hazardous substances.

Nitrate

Only a small portion of the deeper-lying groundwater in Fyn County has an elevated concentra-

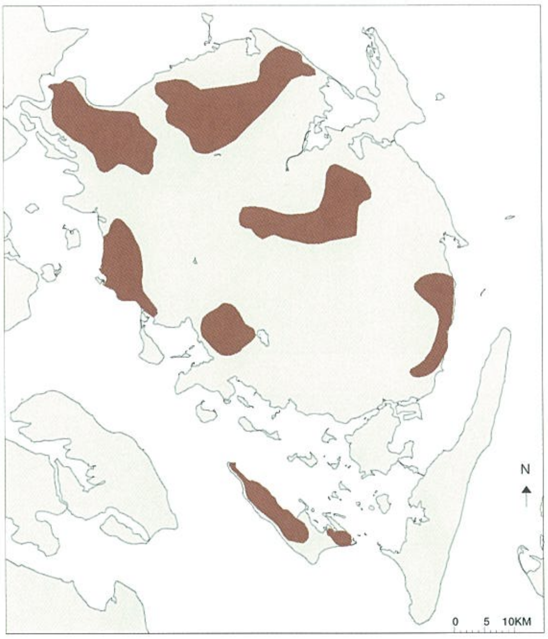


Figure 9.5
Regions in Fyn where the concentration of nitrate in groundwater is elevated (> 5 mg/l) and is considered to pose a problem for the abstraction of drinking water.

Nitrate or nitrate-nitrogen?

When comparing measurements of the nitrate concentration in groundwater with that in streams, lakes, or the sea, it should be remembered that in groundwater the nitrate concentration is expressed as nitrate (NO_3) whereas the concentration in surface waters it is expressed as nitrate-nitrogen (NO_3-N), i.e. only as the nitrogen part of the nitrate molecule. Thus, values given as NO_3 should be divided by 4.43 in order to be expressed as NO_3-N. Consequently, the suggested threshold level of 25 mg NO_3/l (for groundwater) is equivalent to 5.6 mg NO_3-N/l.

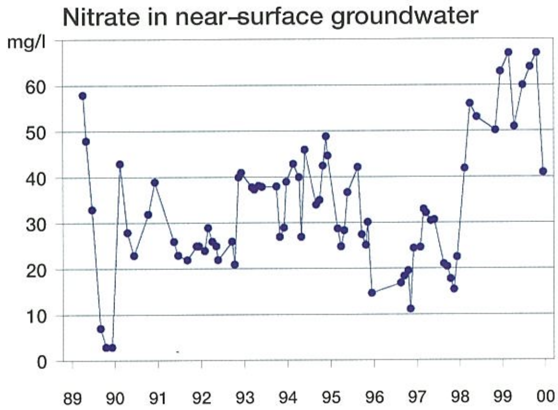


Figure 9.6
Mean nitrate concentration in shallow groundwater (5 m below ground level) at the village of Oure, eastern Fyn. The data are from one of many boreholes examined.

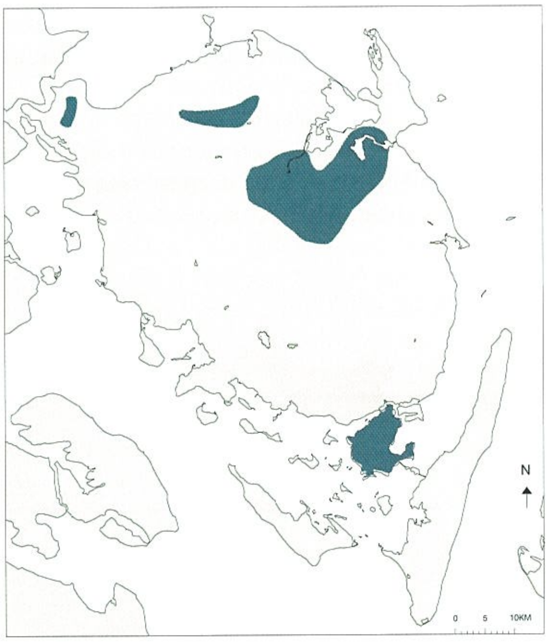


Figure 9.7
Regions in Fyn where the concentration of sulphate in groundwater is considered to pose a potential problem for the abstraction of drinking water.

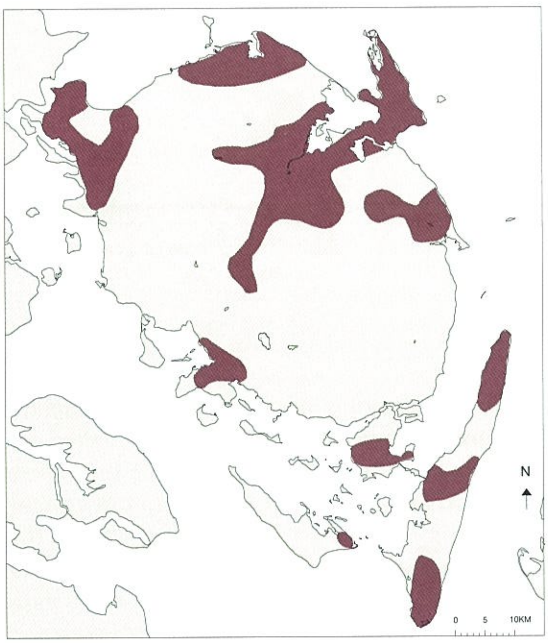


Figure 9.8
Regions in Fyn where the concentration of chloride in groundwater is considered to pose a potential problem for the abstraction of drinking water.

tion of nitrate. This is due to protective clay layers, in which degradation of nitrate occurs. Thus compared with many other Danish counties, nitrate does not currently pose a large problem to waterworks in Fyn County. Water with a nitrate concentration less than 5 mg/l is supplied by 83% of waterworks. This represents 92% of the total amount of water supplied by the County's waterworks. Only a few waterworks supply water in which the nitrate concentration exceeds the recommended upper limit of 25 mg/l, and no waterworks supply water with a nitrate concentration that exceeds the maximum permitted level of 50 mg/l.

The situation is quite different when shallow groundwater is abstracted. Nitrate concentrations exceed the maximum permitted level of 50 mg/l in many private boreholes and wells, as groundwater near the ground surface has been strongly affected by nitrate leached from farm land (Figure 9.6). Annual variation in the concentration of nitrate in shallow groundwater is partly due to variation in the amount of winter precipitation, and the resulting formation of new groundwater. For example, less nitrate was washed into groundwater in 1995/96 and 1996/97.

In certain vulnerable areas, the protective clay layer is either thin or absent. In such regions the groundwater is contaminated with nitrate (Figure 9.5), and over the years there has been an increase in nitrate concentrations (Figure 9.6). These vulnerable areas are unsuitable for the abstraction of water by waterworks. In order to prevent nitrate contamination of groundwater it will be necessary in the future to reduce the use of fertilisers in particularly vulnerable areas.

Sulphate

In general, the concentration of sulphate in groundwater is rising. The primary reasons are the oxidation of sulphur-containing compounds in the soil when the water table falls as a result of water abstraction, and oxidation by nitrate infiltrating through the ground. Infiltration of sulphate from fertilisers used on agricultural land is, however, also an important factor. Elevated concentrations of sulphate in groundwater are already a problem with regard to abstraction of water in some regions (Figure 9.7).

Approximately half of the County's waterworks supply water with a sulphate concentration that exceeds the recommended upper limit of 50 mg/l. This represents 53% of the total volume of water supplied by the County's waterworks. No waterworks supply water with a sulphate concentration that exceeds the maximum permitted level of 250 mg/l.

Chloride

Groundwater chloride concentrations are elevated in many regions in Fyn (Figure 9.8). A number of factors can explain this increase. One reason is percolation of salt spread on roads during the winter, another is chloride infiltration from waste disposal sites and from the use of chloride-containing fertilisers. Natural causes for elevated chloride concentrations include the intrusion of saline waters in areas near the coast, saltwater from old marine deposits, and deep-lying, salt-containing sediments.

As a result, the recommended upper limit of 50 mg/l is exceeded at 32% of the County's waterworks, representing 32% of the total volume of water supplied by the County's waterworks. The maximum permitted level of 300 mg/l is no longer exceeded, as abstraction has been suspended at waterworks unable to meet this requirement.

At a number of waterworks and monitoring areas in the County the concentration of chloride in many boreholes has been rising slowly but steadily. The reason is probably the use of fertilisers containing chloride and/or the salting of roads. Fyn County's Highway & Traffic Department has, over the recent years, conducted a number of promising studies of alternative salting methods with the aim of reducing the amount of salt spread on the County's roads.

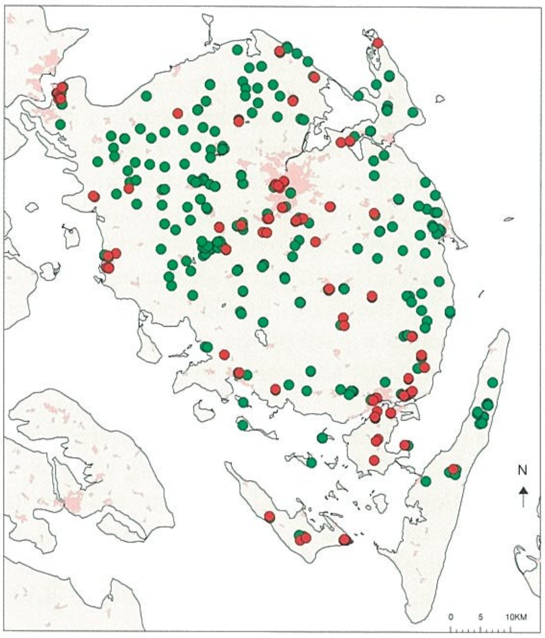


Figure 9.9
Presence of BAM in waterworks boreholes monitored in Fyn County.

Recorded

Not recorded

Pesticides

Pesticides spread in the environment can be degraded chemically or biologically. Contamination can thus take the form of the parent compound and its degradation products. In the assessment of pesticide contamination, no distinction is made between parent compounds and their degradation products. Therefore, both groups of com-

Table 9.3
Overview of pesticides detected in more than one active waterworks borehole in Fyn County up until the end of 1999.

Agent/ Substance	Description	Boreholes examined	Boreholes containing the pesticide	% of boreholes containing the pesticide	Boreholes with levels above the maximum permitted level for drinking water (0.1µg/l)	Marketing status as of 2000
2,6-dichlorobenzamide (BAM)	Degradation product of the non-selective herbicides dichlobenil and chlorthiamide	493	110	22%	54	Prohibited
Hexazinone	Herbicide	430	13	3%	2	Prohibited
Atrazine	Herbicide, triazine	687	16	2%	4	Prohibited
Dichlorprop	Herbicide, phenoxy acid (hormonal agent)	684	13	2%	2	Permitted with restrictions
Mechlorprop	Herbicide, phenoxy acid (hormonal agent)	683	12	2%	1	Permitted with restrictions
Bentazone	Herbicide for pasture and maize fields, etc.	459	8	2%	1	Permitted with restrictions
Desethylatrazine	Degradation product of atrazine	430	7	2%	1	Prohibited
Simazine	Herbicide, triazine	687	9	1%	0	Permitted
Desisopropylatrazine	Degradation product of atrazine and terbutylazine	419	3	1%	0	Prohibited
Pentachlorophenole	Fungicide	495	3	1%	0	No longer sold
Hydroxyatrazine	Degradation product of atrazine	383	2	1%	1	Permitted
Pendimethalin	Herbicide for beet fields, etc.	420	2	<1%	0	Prohibited

pounds are covered by the term pesticides in the following text.

As of 1999, one or more pesticides have been analysed for at 692 out of the County's 773 active waterworks boreholes. As a result, pesticides have been found in 150 active boreholes. Although the analyses include progressively more substances, they only cover a fraction of the several hundred different active substances that have been used in Denmark. In addition, the analyses only examine a part of the possible impurities and additives that are present in the sold pesticide mixtures.

The most problematic pesticide in waterworks boreholes, based on the monitoring to date, is 2,6-dichlorobenzamide (BAM). In addition to BAM, atrazine (and its degradation products), simazine, mechlorprop, and dichlorprop have been detected in many waterworks boreholes. BAM has been detected in 22% of the boreholes in which it has been analysed for (Figure 9.9 and Table 9.3). In half of these, the concentration of BAM exceeded the maximum permitted value for drinking water of 0.1 µg/l (= microgram per litre). BAM is a degradation product of the parent compounds dichlobenil and chlorthiamid, which were marketed in products such as 'Prefix' and 'Casaron G' during 1965-1996. These agents were used, in particular, to hold public and private areas of gravel free from weeds. BAM contamination is, therefore, most evident in urban areas. Dichlobenil is now prohibited in Denmark, while chlorthiamid is no longer marketed.

BAM contamination is found throughout Fyn County, both in sandy regions and in groundwater protected by thick layers of clay. BAM has been detected at depths of up to 50 m below the surface, and the contamination is the result

Table 9.4
Overview of pesticides in boreholes of six selected groundwater regions in Fyn County, examined as part of the national NOVA 2003 monitoring programme.

Agent/ Substance	Filters examined	Filters containing the pesticide	% of filters containing this pesticide	Boreholes with levels above the maximum permitted level for drinking water (0.1µg/l)	Marketing status as of 2000
2,6-dichlorobenzamide (BAM)	80	14	18%	7	Prohibited
Dichlorprop	89	8	9%	2	Permitted with restrictions
Hexazinone	80	6	8%	1	Prohibited
Mechlorprop	89	5	6%	3	Permitted with restrictions
2,6-dichlorobenzoic acid	66	3	5%	0	Prohibited
4-CPP	25	1	4%	0	Unknown origin
Bentazone	80	3	4%	1	Permitted
Atrazine	89	3	3%	0	Prohibited
Hydroxyatrazine	65	2	3%	0	Prohibited
2-M-6-CCP	64	1	2%	0	Unknown origin
Clopyralid	66	1	2%	1	Permitted
Chloridazon	67	1	1%	1	Prohibited
Triadimenol	67	1	1%	0	Withdrawn from market
Metamitron	70	1	1%	0	Permitted
Dichlobenil	72	1	1%	0	Prohibited
Desethylatrazine	80	1	1%	1	Prohibited
Desisopropylatrazine	80	1	1%	0	Permitted
MCPA	89	1	1%	0	Permitted with restrictions
Dinoseb	89	1	1%	0	Withdrawn from market
Simazine	89	1	1%	0	Permitted with restrictions

of contributions from many polluted areas. The prevalence of BAM in groundwater is the result of its parent compounds having been used as non-selective herbicides on non-agricultural land (public and private areas, around industrial buildings etc.) and in orchards.

With the exception of a few boreholes which have consistently high concentrations of several µg/l, the concentration of BAM in most boreholes varies to such an extent that it is difficult to make firm statements on general trends in BAM contamination. However, it does appear that concentrations have not changed significantly since BAM was first analysed for in 1995, and in some boreholes the concentration of BAM has actually fallen. For example, the concentration of BAM in some boreholes at the town of Middelfart has fallen from around 1 µg/l in 1995-1996 to less than 0.1 µg/l today. If the trend for these boreholes continues, it will represent a positive development that has not previously been seen in relation to pesticide contamination of groundwater.

Although BAM is by far the most commonly detected pesticide, the possibility cannot be excluded that one or more pesticides, or their degradation products, that have not been analysed for to date may be present in numerous boreholes.

In the County's designated monitoring areas, which are primarily located in the countryside, the situation is a little different (Table 9.4). Here, the pesticides most often detected are those used on agricultural land. Thus the prevalence of BAM is somewhat lower than in waterworks boreholes, while other substances such as dichlorprop and mechlorprop are found more frequently than in waterworks boreholes.

The aquifer southeast of the town of Kerteminde is widely contaminated with mechlorprop and dichlorprop. The concentrations of the pesticides are constant and not especially high (below the maximum permitted level for drinking water). As the pesticide concentrations are similar throughout the aquifer, the contamination is likely to have originated from the use of pesticides over large areas of land above the aquifer.

Pesticide contamination of groundwater has resulted in the closure of some boreholes, while abstraction from other boreholes has been reduced. Thus, the County's waterworks essentially supply water that does not exceed the maximum permitted level for pesticides. Many waterworks have new boreholes that can be taken into service if pesticides are detected in those in use. In five cases, Fyn County Council has given permission for water from a borehole contaminated with BAM to be piped to a watercourse. The aim is to prevent the spread of contamination to adjacent boreholes. In certain regions of the County, contamination of groundwater with BAM is so extensive that it is difficult to find sufficient uncontaminated groundwater to supply drinking water. The problem is particularly acute on islands such as Ærø and Tåsinge. Consequently, Fyn County Council has issued a 5-year permit allowing Vindeby Waterworks and Landet Waterworks on Tåsinge to purify the drinking water using activated carbon.

MTBE

Methyl–tetra-butyl-ether (MTBE) is used as an anti-knocking agent in unleaded petrol. Up to 100 000 tons of MTBE have been used annually in Denmark, though in recent years MTBE has been used primarily in 98 octane petrol.

In 1997, an investigation by Fyn County showed that MTBE had contaminated groundwater under certain petrol stations that had sold unleaded petrol. Analysis of MTBE is now one of the analyses normally made at petrol stations where the ground has been contaminated as a result of the leakage or spill of petrol.

Waterworks have also started to analyse boreholes likely to be exposed to MTBE. To date, MTBE has been analysed for at 16 active boreholes, and been found to be present at five. In addition, MTBE has been detected in one of nine selected boreholes located in the County's monitoring areas.

Other hazardous substances

As of 1999, the presence of chlorinated solvents has been investigated at 340 active boreholes distributed between 143 waterworks. The compounds analysed for are di-, tri-, and tetrachloroethylene, dichloromethylene, and trichloroethane. The substances have been found at 36 active boreholes at concentrations ranging from trace amounts (below the limit of detection) up to 260 µg/l. Eight active boreholes have concentrations of chlorinated solvents that exceed the recommended upper limit of 1 µg/l.

Chlorinated solvents have been used for many years in the metal industry and by dry cleaners, the latter typically located in towns. As a result, chlorinated solvent contamination is most common in the County's larger towns, for example Odense and Nyborg. The contamination is usually local, though chlorinated solvents have been found over a sizable part of central and south Odense. This contamination probably originates from a large number of sources, and is due to the poor protection of the groundwater.

In some cases, chlorinated solvent contamination has resulted in water abstraction being abandoned. In other situations, groundwater is remediated by pumping to prevent contamination from spreading.

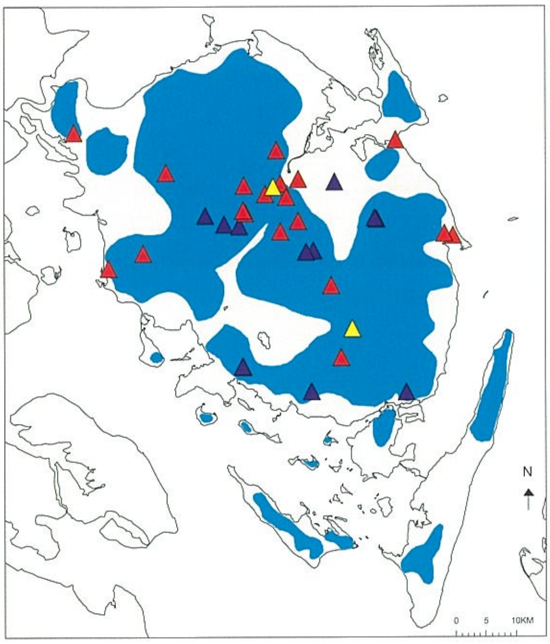


Figure 9.10
Location of the 32 contaminated sites monitored by Fyn County Council due to a perceived threat to groundwater or surface water.

Legend:

Primary pollutants:

- Nutrients/inorganic compounds
- Hazardous substances
- Nutrients and hazardous substances
- Groundwater areas of special interest

Monitoring of contaminated grounds

Remediation of contaminated sites in Fyn County normally begins with the removal of the most highly contaminated soil. If the contamination is located under a building, or has spread to groundwater, different remedial measures are established. The most commonly established are so-called in situ remediation measures, which degrade the contaminants down in the ground in situ or make it possible to pump the contaminants out of the groundwater. Such remedial measures often need to be active for many years before the contamination is reduced sufficiently.

In a number of cases, investigations by Fyn County Council have shown that there is not an immediate need, or the economy, to establish remedial measures. In such situations, development of the contamination is monitored in order to as-

Ringe Gasværk (closed).
The highly contaminated gasworks site in the town of Ringe was cleaned up in 2000 after monitoring showed cyanide to have infiltrated to the primary aquifer.

Photo: Fyn County

sess its effects on groundwater, surface water, or the internal environment of buildings. Monitoring may also have the purpose of following the spread of contamination after a hot spot has been cleaned up.

In 1999, environmental conditions at 34 contaminated sites were monitored by Fyn County Council. This monitoring typically takes the form of following developments in the composition and concentration of contaminants infiltrating groundwater. Consideration of streams, and the risk for explosive gases to spread from waste disposal sites are also reasons for monitoring (Table 9.5). For each site, an individual monitoring programme is produced, and adjusted on a running basis depending on the results of the analyses. Individual sites are monitored from between twice-yearly to every three years.

Of 32 sites monitored for quality of groundwater and/or surface water, two sites are contaminated with nutrients, 18 are contaminated primarily with hazardous substances, while both types of contaminants are involved at the remaining 12 sites (Figure 9.10, Table 9.5). Contamination is increasing at three sites, decreasing at four sites, and stable at 18 sites. Developments at the remaining seven sites cannot be determined due to insufficient data.

The results of the monitoring programme are regularly assessed to determine if monitoring should be adjusted, stopped, or if remedial measures should be introduced. Monitoring by Fyn County Council determined that contaminants had infiltrated the primary aquifer below the now-closed gasworks, Ringe Gasværk, in the town of Ringe in central Fyn. Consequently, Ringe Gasværk was prioritised for clean-up in 2000.

Results of the County Council's monitoring of contaminated grounds are presented in an annual monitoring report.

Reasons for monitoring	
Groundwater contamination	25
Surface water contamination	3
Groundwater and surface water contamination	4
Emission of gases	2
Total	34

Table 9.5 Reasons for monitoring of contaminated sites by Fyn County Council.

Drinking water for the future

In Fyn County there is, in general, sufficient groundwater of good quality to supply the population with drinking water. If this will also be the case in the future is, however, not known. In general, the deeper-lying groundwater contains little nitrate, whereas groundwater near the surface is heavily contaminated with nitrate leached from farm land. Although significant changes in the concentration of nitrate in the deeper groundwater have not been observed during the last 10 years, large amounts of nitrate may be moving downwards. Thus, there is a special need to protect vulnerable areas from leached nitrate.

It is important to ensure that resources spent on one source of contamination are not wasted because groundwater is being simultaneously contaminated via other sources. This can be ensured by considering all potential sources and circumstances that can result in groundwater contamination in each area. In this regard, Fyn County Council is currently mapping all possible sources of groundwater contamination, and the extent of natural protection of the County's groundwater. The work is carried out in close cooperation with the County's 32 municipalities, waterworks, farmers' associations and other stakeholders. It involves mapping of vulnerable areas and zonation of areas for abstraction of future drinking water. The mapping effort will result in actual action plans, which identify the measures to be taken to protect groundwater in each of the areas in which remedial or protective measures are considered necessary. The authorities and other stakeholders must follow the planned measures to ensure that groundwater resources can be protected in the future.

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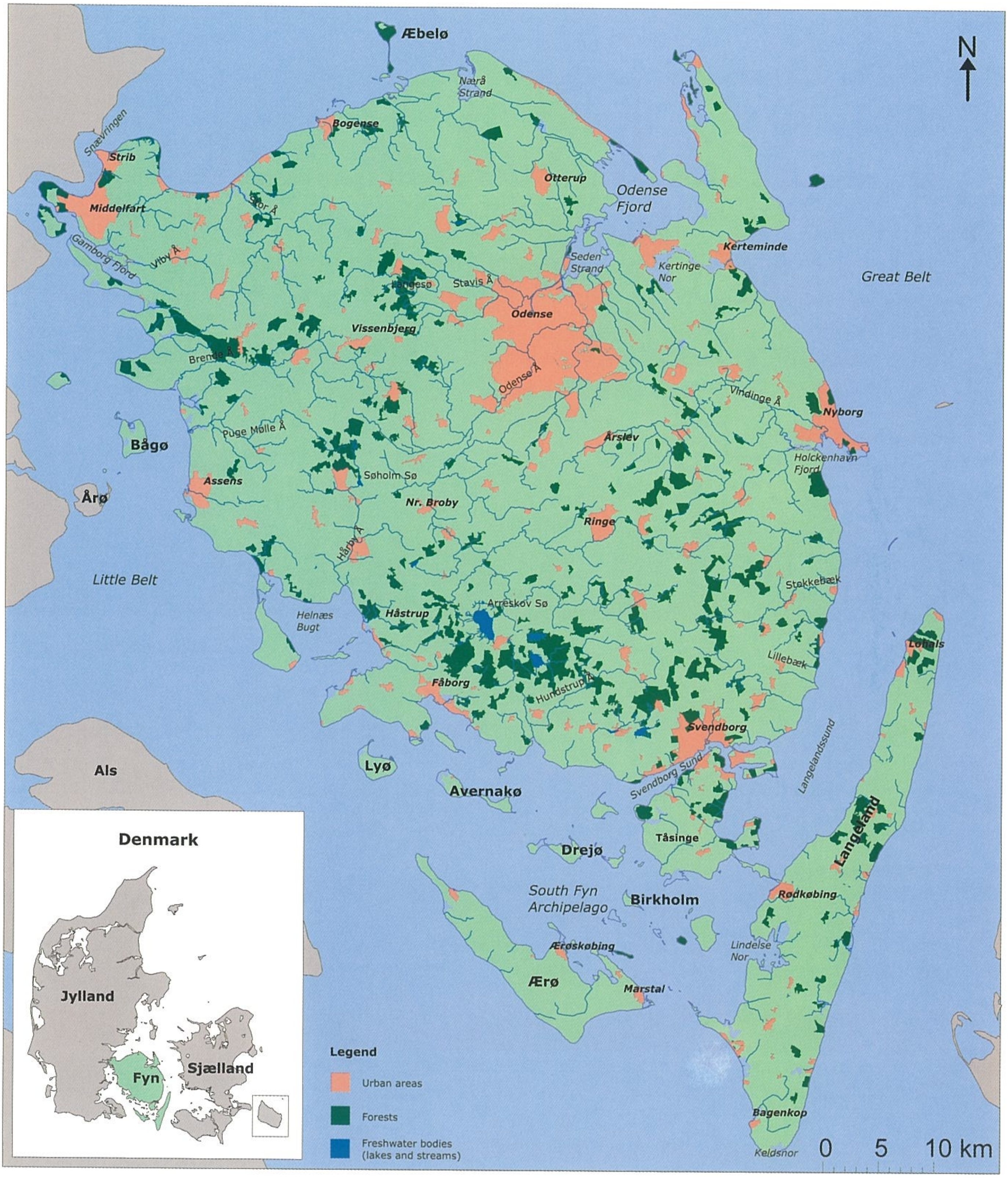
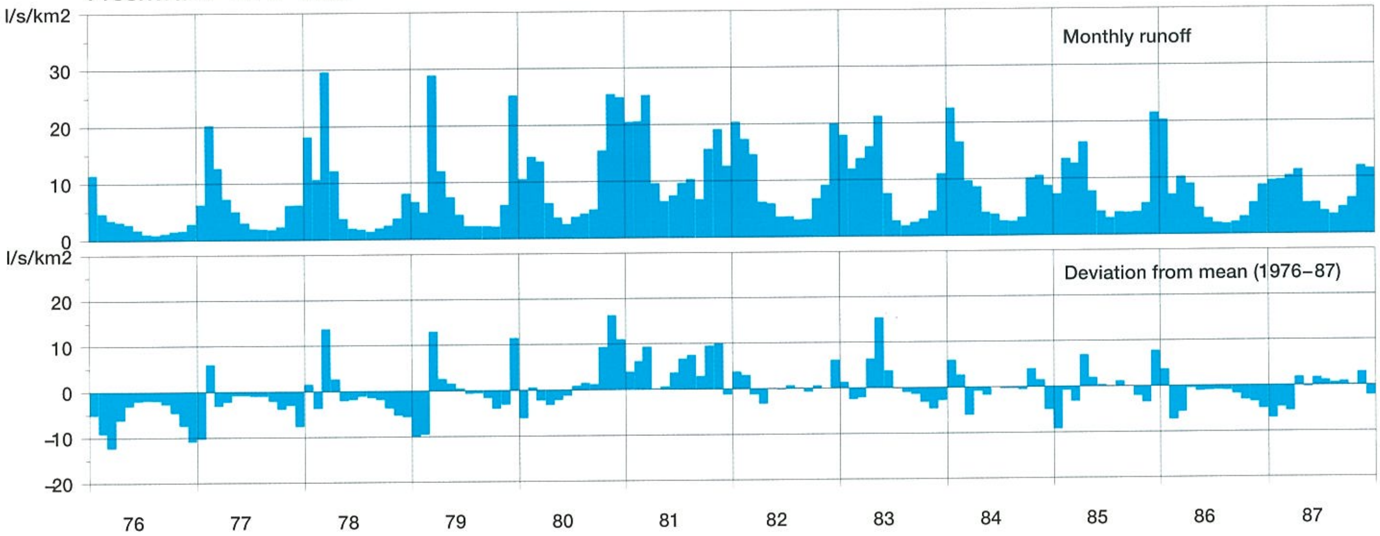
Europe (excerpt)

Fyn County (with Denmark inserted)

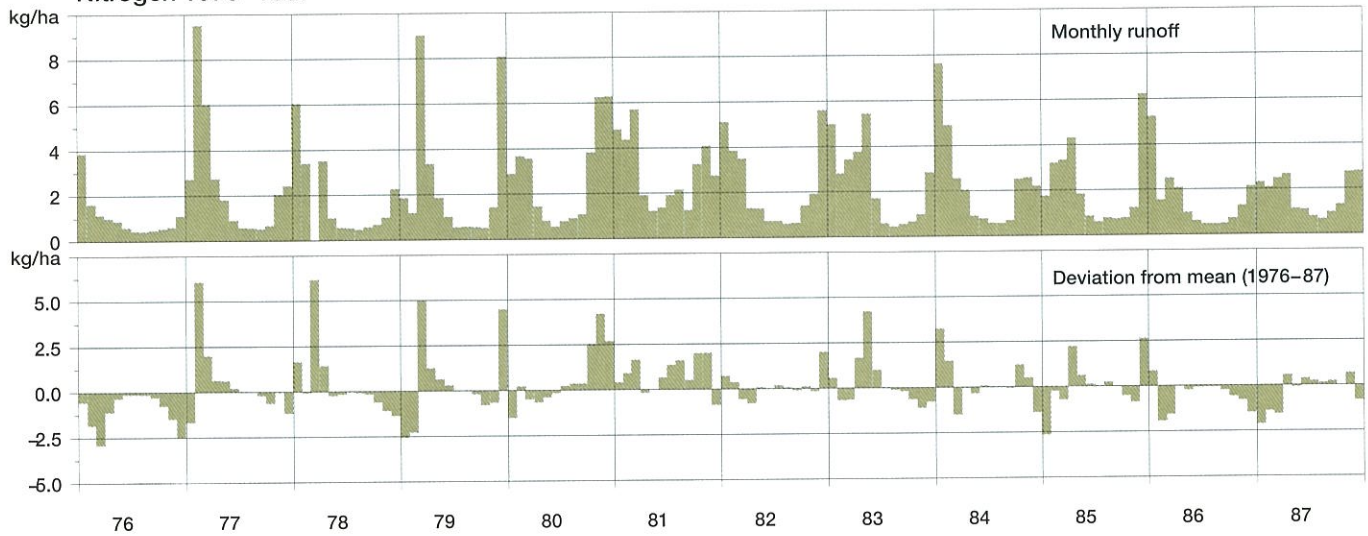


Riverine runoff in Fyn County 1976–1987

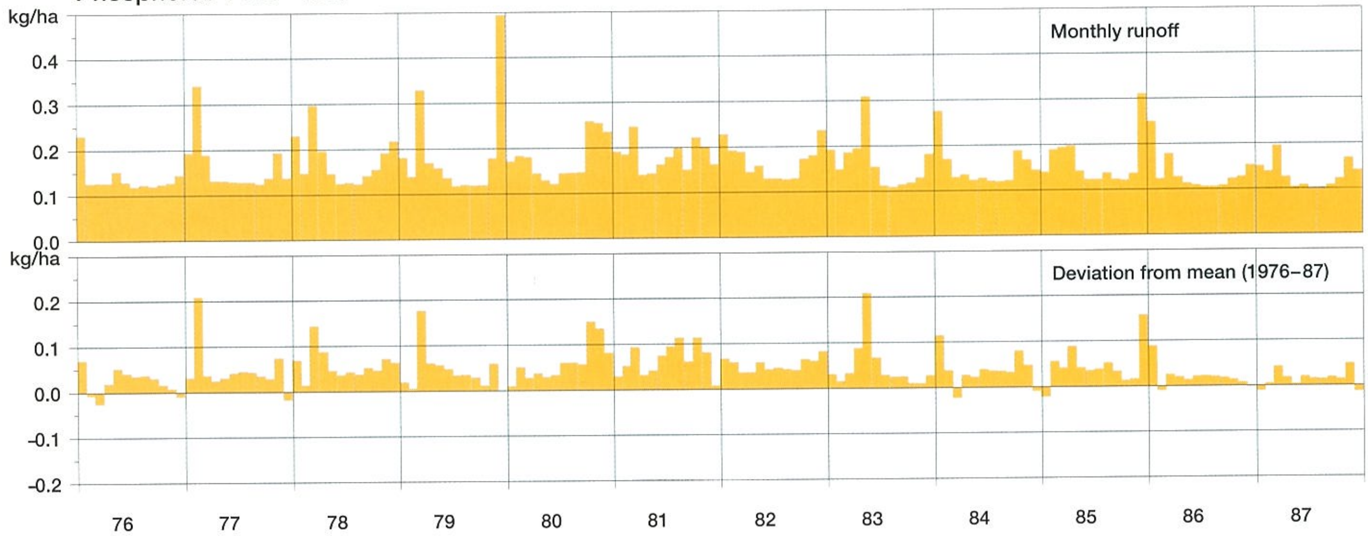
Freshwater 1976–1987



Nitrogen 1976–1987

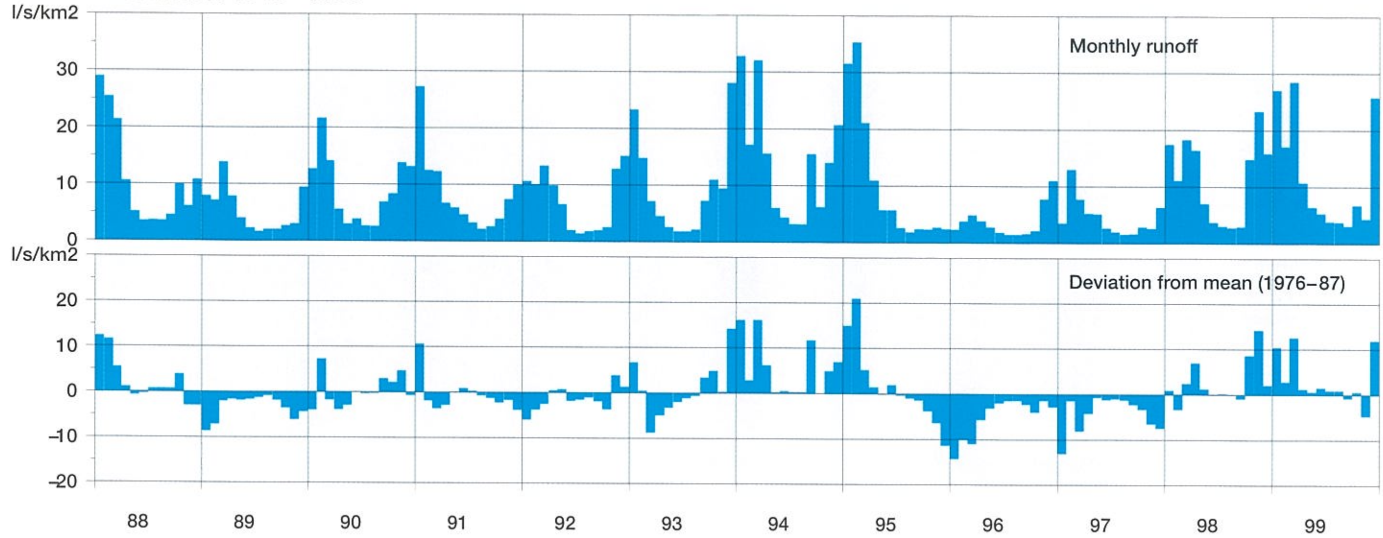


Phosphorus 1976–1987

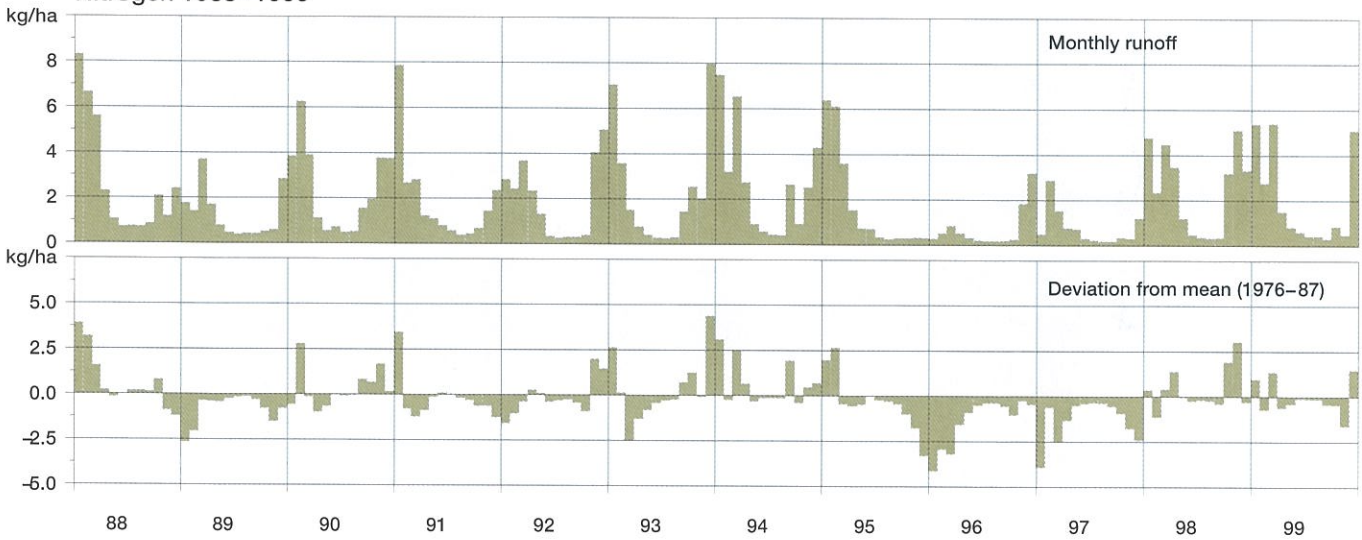


Riverine runoff in Fyn County 1988–1999

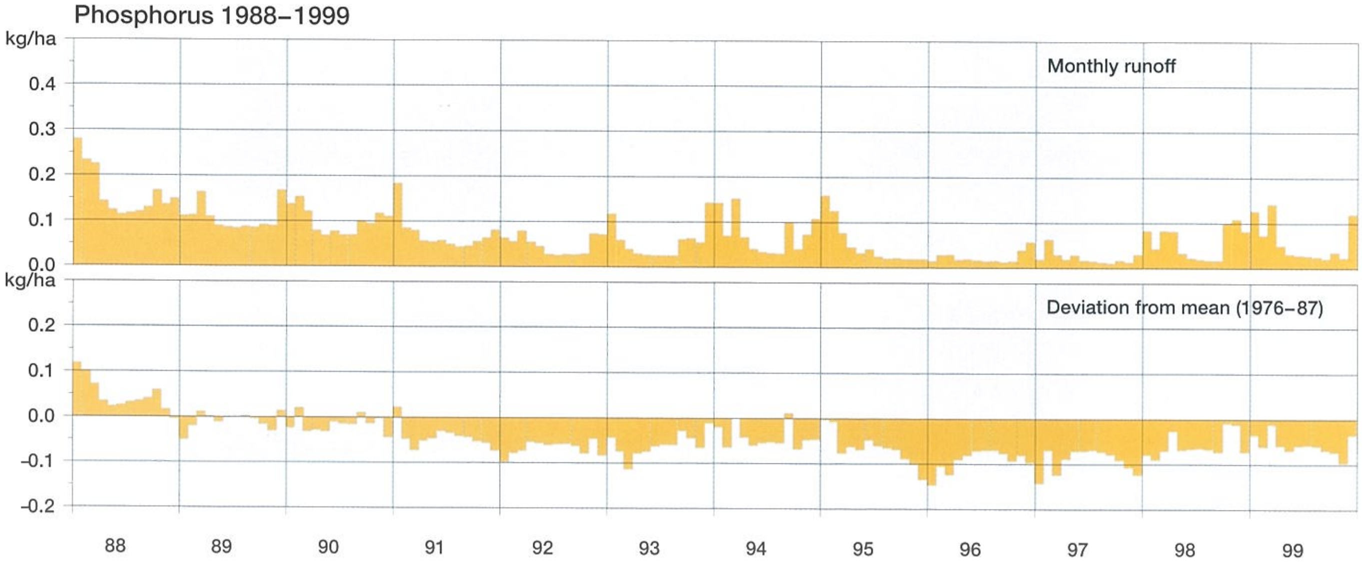
Freshwater 1988–1999



Nitrogen 1988–1999



Phosphorus 1988–1999



Appendix 2A

Pesticides detected in streams in Fyn County during the period 1994-98.

Legend:

- \+ *Approved*
- (+) *Restricted use*
- ÷ *Prohibited/ withdrawn*
- \- *Never approved*
- *nd* *Not detected*
- *na* *Not analysed*
- * *Metabolite*
- ** *Also present as a metabolite of carbosulfan and furathiocarb*

Pesticides found 1994-1998 in streams	Detection level	Odense Å (mixed catchment)			Lillebæk (agricultural catchment)			Forest stream			Approved to be used	
Active substance	µg/l	Max conc. µg/l	Records %		Max conc. µg/l	Records %		Max conc. µg/l	Records %			
			94-97	98		94-97	98		94-97	98	93	98
Herbicides:												
AMPA*	0.01	0.6	100	100	1.1	100	100	nd	0	0	+	+
Atrazine	0.03-0.1	0.4	37	38	1.0	58	21	0.07	4	0	+	÷
Desethylatrazine*	0.05-0.1	nd	0	0	0.7	18	58	nd	0	0	+	÷
Desisopropylatrazine*	0.1	nd	0	0	0.08	0	5	nd	0	0	+	÷
Hydroxyatrazine	0.01	0.016	na	67	0.013	na	100	nd	na	0	+	÷
Bentazone	0.02-0.1	0.3	28	100	10.0	31	0	nd	0	0	+	(+)
Bromoxynil	0.02	0.011	0	17	0.07	6	0	nd	0	0	+	+
Clopyralid	0.05-0.3	0.05	1	0	0.4	9	32	nd	0	0	+	+
Cyanazine	0.05-0.1	0.3	2	0	0.2	2	11	nd	0	0	+	÷
Dichlobenil	0.03-0.1	0.2	27	0	0.2	27	11	nd	0	0	+	÷
2,6-dichlobenzamide*	0.05-0.1	0.2	90	75	0.4	93	100	0.08	4	0	+	÷
Dichloprop	0.02-0.2	0.2	17	38	0.2	8	5	nd	0	0	+	÷
Diuron	0.03-0.1	1.0	50	75	2.0	32	42	nd	0	0	+	(+)
DNOC	0.01	0.053	na	67	nd	na	0	nd	na	0	+	÷
Ethofumesate	0.03-0.2	0.1	13	50	0.6	23	0	nd	0	0	+	+
Glyphosate	0.01	0.7	90	100	2.7	100	100	nd	0	0	+	+
Hexazinone	0.03-0.1	0.08	27	75	4.0	53	5	2.0	78	100	+	÷
Ioxynil	0.03-0.1	0.02	5	0	0.1	18	0	nd	0	0	+	+
Isoproturon	0.05-0.2	1.0	38	75	1.0	42	74	nd	0	0	+	(+)
Linuron	0.1-0.2	nd	0	0	0.6	7	0	nd	0	0	+	+
MCPA	0.02-0.1	0.2	32	50	2.0	31	26	nd	0	0	+	(+)
Mecoprop	0.02-0.1	0.4	46	38	3.0	53	11	nd	0	0	+	(+)
Methabenzthiazuron	0.02	0.044	0	38	nd	0	0	nd	0	0	+	+
Metazachlor	0.05-0.1	nd	0	0	0.1	2	0	nd	0	0	-	-
Pendimethalin	0.05-0.1	0.033	0	50	0.2	0	11	0.010	0	100	+	+
Propyzamide	0.05-0.1	0.8	4	0	0.07	0	5	nd	0	0	+	(+)
Simazine	0.03-0.2	0.3	21	38	0.3	10	16	nd	0	0	+	(+)
Terbuthylazine	0.03-0.1	0.2	35	75	0.4	15	21	nd	0	0	+	+
Deethylterbuthylazine	0.01	0.026	na	83	nd	na	0	nd	na	0	+	+
Tribenuron-methyl	0.01-0.03	0.03	3	na	0.04	2	na	nd	0	na	+	+
2,4-D	0.02-0.1	0.1	11	0	0.2	3	0	nd	0	0	+	(+)
Fungicides:												
Fenpropimorph	0.05-0.1	nd	0	0	0.2	7	0	nd	0	0	+	+
Propiconazole	0.05-0.1	0.08	2	0	0.8	10	0	nd	0	0	+	+
Insecticides:												
Carbofuran**	0.1-0.2	0.4	3	0	nd	0	0	nd	0	0	+	(+)
Diazinon	0.05	nd	0	0	0.04	0	5	nd	0	0	+	(+)
Dimethoate	0.05-0.1	0.7	2	0	0.2	3	0	0.1	4	0	+	+
Esfenvalerate	0.1-0.2	nd	0	0	0.2	7	0	nd	0	0	+	+
Pirimicarb	0.03-0.08	0.07	27	13	3.0	12	11	nd	0	0	+	+
4-nitrophenol*	0.01	0.012	na	17	nd	na	0	nd	na	0	+	÷

Pesticides found 1996-1998 in drains and wastewater Active substance	Detection level µg/l	Field drains Max konc. µg/l	Mixed drains Max konc. µg/l	Outlet from wastewater treatment plants Max konc. µg/l	Approved to be used 93	 98
Herbicides:						
AMPA*	0.01	0.083	1.2	2.0	+	+
Atrazine	0.03-0.1	0.1	nd	nd	+	÷
Desethylatrazine*	0.05-0.1	0.4	nd	nd	+	÷
Desisopropylatrazine*	0.1	0.08	nd	nd	+	÷
Bentazone	0.02-0.1	0.04	0.9	nd	+	(+)
Bromoxynil	0.02	0.02	0.06	nd	+	+
Clopyralid	0.05-0.3	0.05	nd	nd	+	+
Dichlobenil	0.03-0.1	nd	0.06	nd	+	÷
2,6-dichlobenzamide*	0.05-0.1	0.09	0.3	0.1	+	÷
Dichlorprop	0.02-0.2	nd	nd	0.04	+	÷
Diuron	0.03-0.1	nd	0.2	0.1	+	(+)
Glyphosate	0.01	0.062	1.3	0.4	+	+
Isoproturon	0.05-0.2	0.5	3.0	nd	+	(+)
MCPA	0.02-0.1	0.06	0.02	nd	+	(+)
Mecoprop	0.02-0.1	0.02	0.2	0.08	+	(+)
Pendimethalin	0.1	nd	0.1	nd	+	+
Simazine	0.03-0.2	nd	0.1	0.4	+	(+)
Terbuthylazine	0.03-0.1	0.4	nd	0.1	+	+
Fungicides:						
Fenpropimorph	0.05-0.1	0.2	0.07	nd	+	+
Prochloraz	0.2	nd	nd	0.2	+	+
Propiconazole	0.05-0.1	1.0	0.2	0.1	+	+
Insecticides:						
Carbofuran**	0.1-0.2	0.1	0.04	nd	+	(+)
Diazinon	0.1	nd	nd	0.5	+	(+)
Pirimicarb	0.03-0.8	nd	0.03	nd	+	+

Pesticides detected in drains and treated wastewater. Drains are divided into those that solely drain agricultural land (field drains), and drains that, in addition to draining fields, also collect water from scattered homes and farmyards (mixed drains). Discharges from wastewater treatment facilities comprise only two samples from the Ejby Mølle facility in the City of Odense, collected on 25-26 June and 26-27 June 1997.

Legend:
- \+ *Approved*
- (+) *Restricted use*
- ÷ *Prohibited/ withdrawn*
- nd *Not detected*
- * *Metabolite*
- ** *Also present as a metabolite of carbosulfan and furathiocarb*

Riverine nutrient runoff for Fyn County 1976-1999											
Year	Riverine runoff	Nitrogen runoff					Phosphorus runoff				
	l/sec/km²	Point tons/yr	Diffuse tons/yr	Total tons/yr	Total kg/ha	Diffuse kg/ha	Point tons/yr	Diffuse tons/yr	Total tons/yr	Total kg/ha	Diffuse kg/ha
1976	3.1	1829	2584	4413	13	7	539	38	577	1.65	0.11
1977	6.2	1831	8806	10637	31	25	543	142	685	1.97	0.41
1978	8.0	1770	8770	10540	30	25	532	199	730	2.10	0.57
1979	8.8	1716	8719	10435	30	25	514	275	788	2.26	0.79
1980	10.9	1770	9408	11178	32	27	520	218	738	2.12	0.63
1981	13.7	1687	10414	12101	35	30	509	251	760	2.18	0.72
1982	9.5	1741	7553	9294	27	22	549	155	704	2.02	0.45
1983	9.5	1647	8159	9806	28	23	502	178	680	1.95	0.51
1984	8.6	1722	7997	9719	28	23	520	117	637	1.83	0.33
1985	8.7	1773	7143	8915	26	20	506	169	675	1.94	0.49
1986	6.5	1699	4774	6473	19	14	470	97	567	1.63	0.28
1987	7.8	1761	5538	7299	21	16	412	133	544	1.56	0.38
1988	11.1	1868	9518	11386	33	27	475	199	675	1.94	0.57
1989	5.4	1413	3829	5242	15	11	372	75	446	1.28	0.21
1990	9.0	1447	8471	9917	28	24	292	126	418	1.20	0.36
1991	8.3	1098	6706	7803	22	19	193	107	299	0.86	0.31
1992	7.4	963	7167	8130	23	21	118	84	202	0.58	0.24
1993	9.5	831	8986	9816	28	26	107	128	235	0.67	0.37
1994	14.3	900	10487	11387	33	30	117	192	310	0.89	0.55
1995	10.3	716	6557	7273	21	19	78	133	212	0.61	0.38
1996	3.8	571	2404	2975	9	7	52	48	100	0.29	0.14
1997	4.5	531	2652	3183	9	8	42	56	98	0.28	0.16
1998	11.4	682	9533	10215	29	27	57	184	241	0.69	0.53
1999	12.0	697	7669	8366	24	22	61	185	246	0.71	0.53
1976-1987:											
Mean	8.4	1746	7489	9234	26	21	510	164	674	1.93	0.47
Max.	13.7	1831	10414	12101	35	30	549	275	788	2.26	0.79
Min.	3.1	1647	2584	4413	13	7	412	38	544	1.56	0.11
1989-1999:											
Mean	8.7	895	6769	7664	22	19	135	120	255	0.73	0.34
Max.	14.3	1447	10487	11387	33	30	372	192	446	1.28	0.55
Min.	3.8	531	2404	2975	9	7	42	48	98	0.28	0.14

This
report reviews 25 years of
monitoring of the aquatic environment
in Fyn County, Denmark, including the
present environmental state as well as major trends.
It describes the quality of streams, lakes, coastal
waters, and groundwater, and addresses the major
causes (i.e. the practices in agriculture, and point
sources like households, industry, and traffic) why
international, national, and regional objectives
are not met. Finally, the report points at the
measures necessary to meet these
objectives.

Fyn County Council is one of 16 regional environmental authorities in Denmark that has monitored the quality of the aquatic environment since the early 1970s. This monitoring is the template for environmental planning and administration necessary to protect waterbodies against pollution and other human impact. Further, it is a key element in the national 'Action Plan for the Aquatic Environment' that was approved by the parliament in 1987 in order to reduce the impact from nutrients. In 1998, the State and the county councils agreed on a revised monitoring programme - 'NOVA 2003' - adding more weight to the monitoring of hazardous substances. Yearly, the authorities spent about 27 million Euro combined on monitoring in order to evaluate the environmental effects of investments in the field of wastewater treatment and environmental improvements in the agricultural sector. These investments exceed 2 700 million Euro.