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Environmental Impacts of Nutrient Emissions in Denmark

Ministry of the Environment, Denmark
National Agency of Environmental Protection

Miljøministeriet **Miljøstyrelsen**

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1985
Nr. 1 : Miljøstyrelsens handlingsplan 1985-1990
Nr. 2 : Sløjfning af olietanke

1986
Nr. 1 : Anvendelse af overskudshalm

1987
Nr. 1 : Affaldsredegørelse
Nr. 2 : Danish waste policy
Nr. 3 : Atomkraftværker nær Danmark
Nr. 4 : Pant
Nr. 5 : Kviksølvredegørelse

1988
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Nr. 2 : Fosfor – kilder og virkninger

1989
Nr. 1 : Bly

1990
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Preface

In 1985, the Danish Parliament took its first initiative to reduce the environmental impacts of nutrient emissions, the NPO Action Plan. This Plan was predominantly directed towards reduction of nitrogen emmisions from agriculture, in particular related to use of manure and slurry.

In 1987, the Action Plan for the Aquatic Environment was established as a further development of the former plan. Now nutrient emmisions from domestic and industrial waste became part of the Plan, and overall targets was decided upon – a 50% reduction in nitrogen emmisions and a 80% reduction in phosphorus emmisions by 1993.

In order to improve the scientific basis for the various reduction measures, comprehensive research- and monitoring programmes were initiated. The NPO-research programme on nitrogen and phosphorus in soil, groundwater and surface water systems has been completed recently, and other programs on waste water treatment and marine ecosystems are presently being executed. Also, the first comprehensive reporting on the national monitoring network was published in 1990.

This report summarizes the results of these research- and monitoring programmes, including recent supplementary information obtained from national and international research institutions. It contains an integrated, up to date picture of the complete transport, tranformation and impact of nutrient emmisions in the Danish environment.

The report was written in cooperation with the counties and a large number of Danish research institutions, in particular, the National Environmental Research Institute, the Geological Survey of Denmark and the Danish Research Service for Plant and Soil Science.

1. Introduction

During the past decades an increasing deterioration has been observed in the Danish aquatic environment. This includes too high nitrate concentrations, leading to excessive growth of algae in fresh and marine waters, oxygen depletions, fish mortality, etc. These occurrences can be ascribed to an increased load of the aquatic environment with nitrogen and phosphorus.

Nitrogen and phosphorus with the chemical symbols N and P are as nutrients important conditions for the growth of organic matter in algae and plants in the aquatic environment.

Under natural conditions a balance exists between the emission of nutrients and the growth of organic matter ensuring a stable community of plants and animal species. But if the supply of nutrients is increased, this balance may be disturbed since an increased algae production makes the water so turbid that living conditions for plants and animals are drastically changed. Also, decomposition of the increased amount of organic matter will cause increased oxygen consumption which under adverse conditions may lead to oxygen depletion and fish mortality.

Moreover, increased percolation of nitrogen into the ground water may increase the nitrate content of the drinking water in exceedance of the limits which are considered necessary to ensure an acceptable drinking water quality.

1.1. Sources of the nitrogen load

Waste water contains some nitrogen, but the main source of nitrogen discharge is related to current farming practices. While, in a non-cultivated area, the loss of nitrogen is very small, supply of fertilizers to obtain high production levels in modern farming inevitably results in loss of nitrogen which in many cases is intensified by inappropriate fertilization practices. During the past 30 years, there has almost been a doubling of total fertilizer inputs to Danish arable soil, causing significantly increased losses.

Part of the loss, the ammonia volatilization, will be carried through the atmosphere and deposited again with precipitation or directly from the air. This source forms a considerable part of the nitrogen load in marine areas and noncultivated areas.

The remainder of the nitrogen loss percolates from the root zone and further on to the ground water. In areas with tile drains, a considerable part will be carried directly into the watercourses. Some of the nitrogen reaching the ground water will be removed through natural reduction processes. But the rest will reach the streams, because a considerable part of the run-off to these stems from ground water.

Especially in wetlands, lakes and inlets, a considerable removal of nitrogen may take place, so that only part of agriculture's nitrogen discharge reaches the coastal waters.

1.2. Sources of the phosphorus load

The main source of the phosphorus load is the waste water discharges from housing and industry. This source has increased heavily during the past 20-30 years, as a result of the construction of sewers, and because no treatment of phosphorus has been carried out in most cases. Although the input of phosphorus to arable soil is very considerable, only a relatively small part is lost through drainage water and soil erosion.

Phosphorus is carried through the stream systems, but, unlike nitrogen, no actual removal of phosphorus takes place. Phosphorus will therefore reach the coastal waters, unless it is deposited as phosphorous sediments at the bottom of lakes and watercourses.

1.3. Sources of the organic matter load

The main source of production of organic matter in the environment is the growth which occurs as a result of nitrogen and phosphorus discharges. But direct discharge of organic matter with waste water may have a large local impact where decomposition results in poor oxygen conditions and impoverishment of fauna and flora.

1.4. Reduction of emissions of nutrients

It is on the basis of the above, the deteriorating conditions of the aquatic environment can be explained. Increased discharges from agriculture and of waste water have caused an increase in the nitrate content in ground water, increased production of algae in lakes and marine areas leading to oxygen depletion and fish mortality.

In order to reverse this development, the Danish Parliament has adopted a number of measures to control discharge of nutrients.

A NPO Action Plan was adopted in 1985, especially directed against nitrogen discharges caused by use of animal manure. At the same time a considerable number of studies were implemented in a NPO Research Programme, in order to improve the understanding of the interrelationships between use of fertilizer and the effects on the aquatic environment.

In 1987 an Action Plan for the Aquatic Environment established additional measures against agricultural emissions and also directed its efforts against waste water discharges from municipal and industrial treatment plants. The goals of the Plan are a reduction of the discharges of nitrogen and phosphorus to the aquatic environment of 50% and 80%, respectively.

At the same time a comprehensive monitoring programme was implemented together with a number of further research programmes, including a marine research programme, a research programme concerning waste water treatment and a research programme on agricultural catch-crops.

This Report summarizes the results of the above mentioned programmes together with other reseach results obtained in the last five years.

2. Sources of nutrient emissions

In Chapter 2 the individual types of sources are discussed in detail.

The increased input of nutrients to the aquatic environment can be referred to a great number of sources.

The main source of nitrogen emissions is found in the losses from farming. Modern farming involves use of large amounts of nitrogen and the losses thus become considerably larger than in natural areas. No doubt, increased input of fertilizers means increased production, but existing farming practices have resulted in increasing loss of nitrogen, all the same. The loss takes place partly by way of leaching to ground waters, watercourses and lakes, partly by way of volatilization to the atmosphere. Such nitrogen losses show a most complicated interrelation with type of crop, soil, climate and farming practices, and as a result they show great variations from one field to another, from one year to another. Farming also gives rise to loss of phosphorus, but the loss is small compared with the amounts of phosphorus added as fertilizer.

The main source of phosphorus emissions is found in the discharges from the treatment plants for domestic and industrial waste water. To this comes contributions from rainwater overflows to sewers and waste water discharge from habitation in the open land. Urban waste water also contains nitrogen, but considerably less than the emissions from agriculture.

The main part of industrial waste water is treated in the municipal treatment plants, but some of it, often from very large industries, is discharged individually. Fish breeding, moreover, in both fresh water and marine fish farms, cause discharges of nutrients.

Combustion of fossil fuels such as coal, oil and petrol in connection with power production and transport also cause considerable discharges of nitrogen to the atmosphere.

Discharges to the atmosphere of gaseous nitrogen compounds from agriculture, energy production and transport all contributes to the atmospheric transport. Therefore, nitrogen compounds in the atmosphere orignate from Danish as well as foreign sources. Part of the nitrogen compounds are deposited with precipitation or direct by dry deposition. As a result, the atmospheric nitrogen contribution is important, particularly in natural areas and in marine areas.

2.1. Agriculture

Nitrogen requirements

The large plant production in modern agriculture requires large amounts of nutrients. As many of the crops – and thereby the nutrients – are harvested, it is necessary to fertilize the soils. In more natural ecological systems, nutrients re-circulate to a very high degree. The high nutritive content in the soil and the continuous addition of nutrients easily lead to losses of nutrients to the environment. Great care is therefore necessary with respect to fertilizer use and management in order to avoid eutrophication of the environment. This is particularly true of nitrogen which is easily moved from one place to another, because it occurs in compounds which can be leached from the soil or escape to the atmosphere.

2.1.1. Input of fertilizers to the crops

Nitrogen requirements of crops differ, and therefore guiding standards have been set up for the application of nitrogen to agricultural crops based on a great number of yield experiments in local farmers' and smallholders' associations (table 2.1).

	Kg N per ha per year
Spring barley after barley	130
Spring barley in crop rotation	110
Spring barley after clover	80
Winter wheat after cereals	180
Foddersugarbeet	180
Foddersugarbeet with animal manures	110
Spring rape	180
Winter rape	200–250
Grass for cutting	350
Pea	0

Table 2.1

Guiding standards for nitrogen requirements of important and characteristic crops. (Nitrogen is added by way of commercial fertilizers or ammonia-N in animal manure). (According to the Agriculture's Information Office 1990).

The said nitrogen amounts represents the average economical optimum and not the amounts which give the maximum plant yield. The optimum yield in economic terms is generally lower than the maximum yield, as expenses on factors of production, such as fertilizers, increase more than the extra profit from sale of the crops.

Nitrogen requirements of the crops may be covered by:

- Commercial fertilizers with nitrogen in the form of nitrate, ammonium or ammonia,
- animal manure with nitrogen in the form of both ammonium-N and organic-N (figure 2.1),
- crop residue, with nitrogen especially as organic-N.

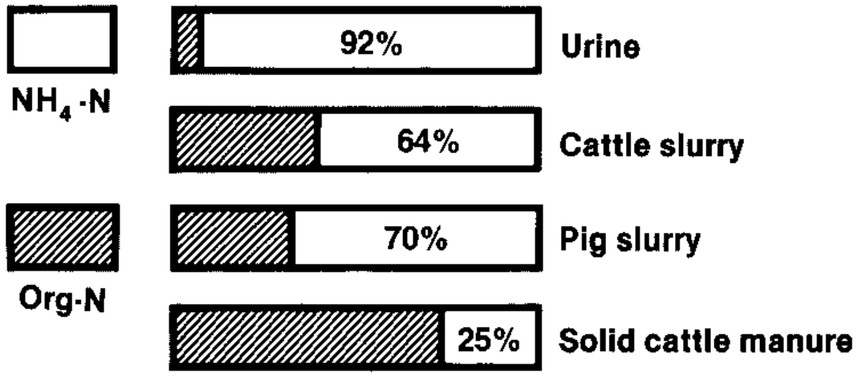

Figure 2.1

Nitrogen content of animal manure. For each category the total nitrogen content is divided into organically fixed nitrogen and ammonium-nitrogen, NH_4-N (Danish Research Service for Plant and Soil Science, 1989).

Nitrogen in the form of nitrate and ammonium may be assimilated directly from the soil by plants, whereas organic-N must first be converted, e.g. mineralized to ammonium. Ammonium from both commercial fertilizers and animal manure can be converted in the soil into nitrate, and in practice, therefore, plants take up more nitrate than ammonium.

Nitrogen in precipitation

In addition to fertilizers, nitrogen compounds are deposited from the atmosphere. These nitrogen compounds have been formed partly by combustion of fossil fuels, partly they stem from previously evaporated ammonia from animal manure.

Nitrogen fixation

Leguminous plants, such as clover and peas, do not need nitrogen fertilizers (cf. table 2.1) as, by means of certain bacteria in root nodules, they can directly fix free nitrogen off the air and utilize it. Generally, leguminous plants can fix up to 300 kg nitrogen per ha per year from the air. Peas, however, can fix only approx. 200 kg nitrogen per ha (Jensen 1990).

Mineralization

Mineralization of organic nitrogen (in the form of straw, roots, animal manure, etc.) into ammonium takes place when the temperature and soil humidity are sufficiently high. Figure 2.2 shows partly an estimate of the course in a normal year, partly measured values in two very mild winters where mineralization was allowed to continue unimpeded the whole year.

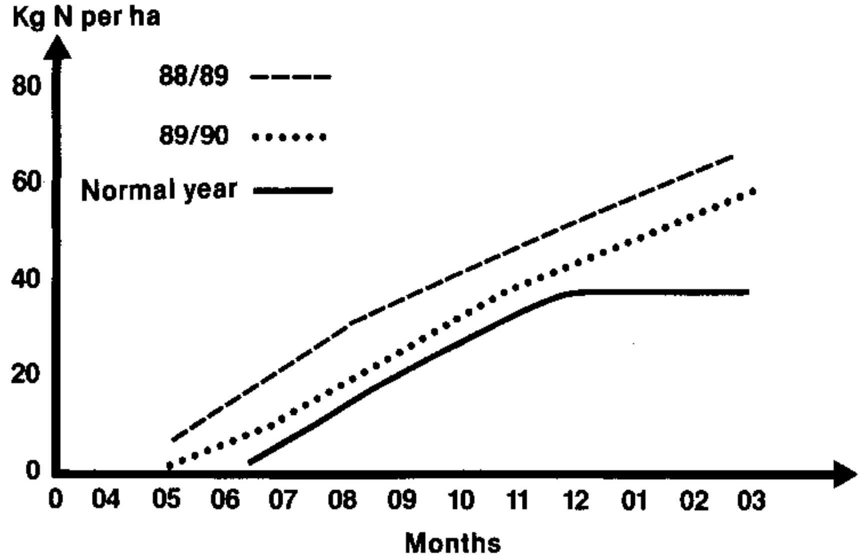

Figure 2.2 **Estimate of the accumulated nitrogen-mineralization in a normal year and the mineralization measured by Lind et al. (1990) in a sandy clay soil in 1988-89 and 1989-90. The nitrogen release stems from plant and fertilizer residues added in the preceding years.**

Mineralization increases with higher pH value in the soil. This implies an increased risk of increased mineralization and thereby increased leaching by limeing.

Ammonium from mineralization is retained by soil minerals and must therefore be converted into nitrate before an actual risk of leaching arises. The formation of nitrate decreases with decreasing soil temperatures and practically stops at soil temperatures below 4 °C. This means that cold winters limit formation of nitrate and thereby the risk of leaching.

Nitrogen in animal manure

Since a considerable part of the nitrogen in animal manure is in organic form, it is not possible directly to compare the fertilizer value of commercial fertilizers and animal manures. In the planning of fertilization, a smaller utilization degree is therefore attributed to animal manure, so that the fertilization value of 100 kg nitrogen in animal manure is estimated lower than the fertilization value in 100 kg nitrogen in commercial fertilizers. Depending on especially time of spreading and type of manure, the utilization degree of total-N in manure may vary from 10 to 60-70% (Pedersen and Østergård 1990).

As shown in figure 2.3, the yield depends strongly on when the manure in spread, as it has the greatest effect if spread just before the growth season.

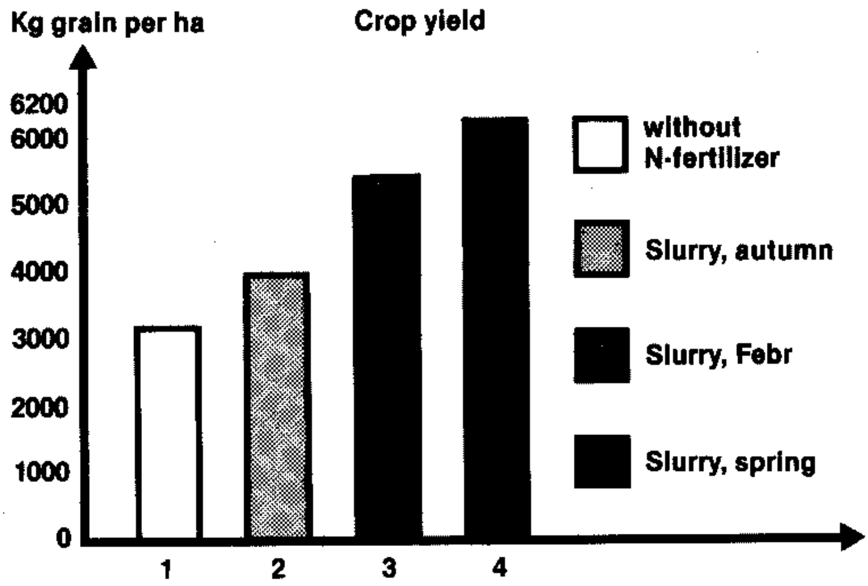

Figure 2.3 **Dependence of wheat yield on the time of spreading of animal manure in a clay soil. 1. without nitrogen fertilizer. 2, 3, and 4 have all received manure slurry with 150 kg ammonium-N, but at different times.** (Danmarks Statistik et al. 1990).

Since organic nitrogen is mineralized over a longer period of time, previously spread animal manure and last year's crop will have a residual fertilization effect on a coming crop. Nitrogen requirements of the crop, as shown in table 2.1, must therefore be adjusted according to last year's fertilizer treatment.

The climate in the winter period has a considerable effect on the amount of nitrogen available to the crop in the spring. A preceding rainy winter with considerable leaching (or a cold winter with small mineralization) leaves a low content of nitrate in the soil in spring. Conversely, a winter with a combination of low leaching and mild weather will leave a particularly high content of nitrate.

Determination of the content of nitrate and ammonium in the soil late in the winter are therefore used to adjust the standard nitrogen dosing of the crops, as they are shown in table 2.1. This takes place by means of the so-called square grid, where the nitrate content in the soil is determined in a large number of fields situated all over the country (Østergård and Mamsen 1990). The square grid is well-suited to support the fertilization planning and may in future be used for surveys of leaching too.

2.1.2. Leaching of nitrogen

In the summer, plants are able to assimilate and evaporate precipitation. As a result, no percolation takes place from the root zone. At the same time, plants take up a considerable part of the nitrate dissolved in the soil water. But as autumn passes, evaporation declines, and if there is no plant cover neither will there be uptake of nitrogen in soil water. The water content of the soil increases and percolation begins. Depending on precipitation and temperature, it continues throughout the winter, until it ceases some time during the spring.

Nitrate may be leached

Substances dissolved in water may, therefore, leach during this period. This goes especially for nitrate and, to a certain extent, for organic matter. Ammonium, on the other hand, is fixed to the clay particles of the soil.

As a result of this, the nitrate left in the soil after harvest is lost. Moreover, a considerable part of the nitrate added as fertilizer in the autumn together with nitrate mineralized during the leaching period is lost. A limitation of the nitrate content in the soil water is therefore decisive in order to obtain a reduction in agriculture's leaching of nitrogen.

It is obvious that leaching is very dependent on the supply of fertilizers, straw ploughing, type of crop, type of soil and weather conditions (especially winter precipitation and temperature). Input of fertilizers and nitrogen absorbtion of the various types of crops naturally have a decisive impact on the content of nitrate in the soil. The temperature is decisive for the mineralization and formation of nitrate from organic matter, whereas precipitation and type of soil in particular have an effect on the amount of percolation and its progress over time. As a result of this, leaching may vary considerably, from one field to another, from one month to the next, and from year to year.

Therefore, it is very difficult to perform direct measurements of the leaching. On account of the great variations of the nitrate content, soil water samples have to be collected at short intervals. It is therefore only in connection with research projects that direct leaching measurements have been carried out.

Measurements carried out by the Danish Research Service for Plant and Soil Science show a very considerable variation in the leaching, from 5 to, in extreme cases, 200 kg N per ha per year. The variation depends on crop, type of soil and climatic conditions. As a very rough average level for these many leaching measurements, the order of 55-70 kg N per ha per year may be given.

An example of one of the latest measurements carried out is shown in figure 2.4., where spring barley was the only crop used in all cases (Lind et al. 1990). It must be taken into account that the period in question was characterized by extremely mild winter months and that the figures cannot be considered as being representative. Nevertheless, the figures shows a number of characteristics concerning leaching from agricultural land.

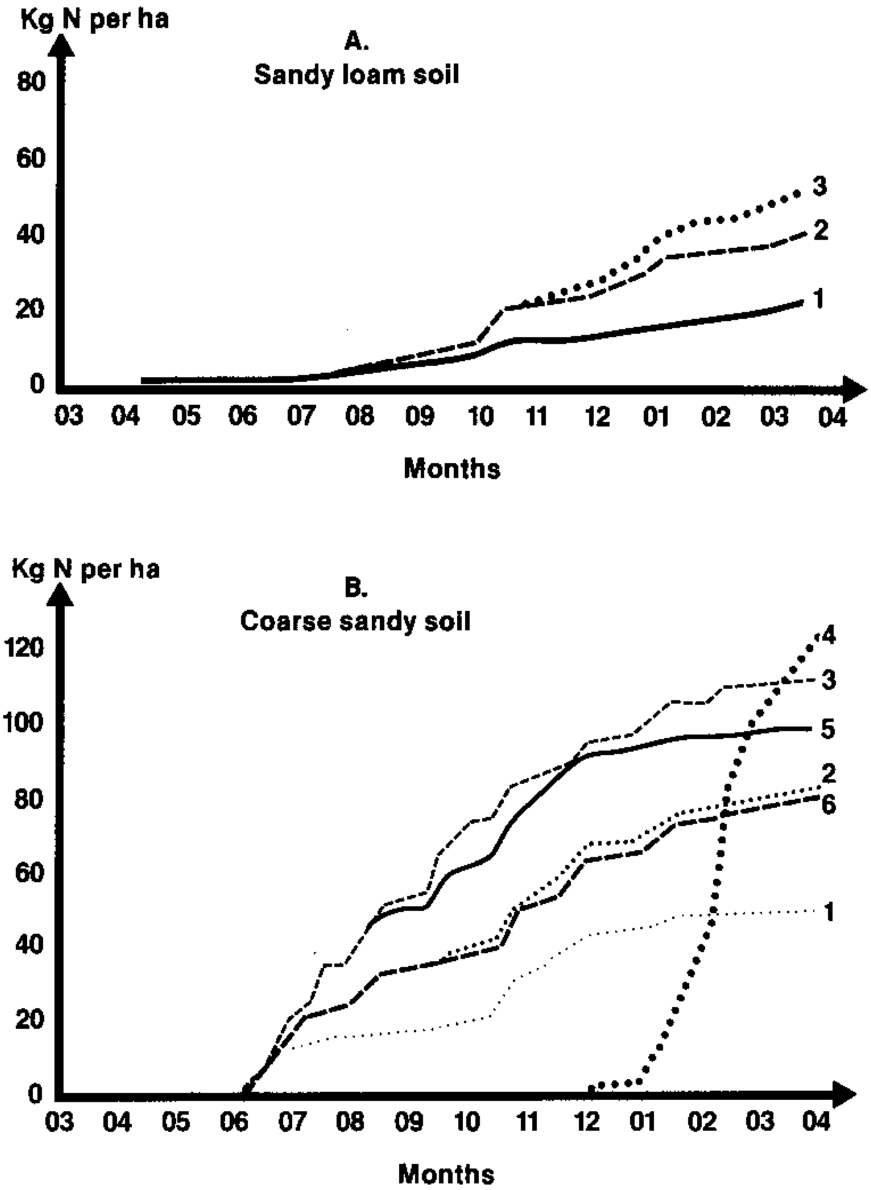

Figure 2.4 **The summarized leaching of nitrate-N in kg/ha for two soils. The crop was in all cases spring barley.**
In the sandy loam soil (A) in 1988-89 three treatments were used: A1: no nitrogen fertilizer, A2: 100 kg N as ammonium-N in manure slurry in the spring, A3: 133 kg N as commercial fertilizer.
In the coarse sandy soil (B) in 1987-88 six treatments were used: B1: no nitrogen fertilization, B2: 55 kg N in the form of ammonium-N in manure slurry in the spring, B3: 110 kg ammonium-N i manure slurry in the spring, B4: 110 kg ammonium-N in manure slurry in the autumn, B5: 110 kg ammonium-N in manure slurry in the spring with a catch-crop, B6: 120 kg commercial fertilizer. (Lind et al. 1990).

Figure 2.4.A shows a clay soil near Askov, Jutland and 2.4 B a sandy soil near Jyndevad, approximately 50 km to the south. Thus, there is a relatively small difference in the climate of the two localities. It clearly appears that leaching is largest in the sandy soil, (see e.g. A3 and B6, A2 and B3).

It appears from experiments Bl, B2 and B3 that there is a connection between supply of fertilizers and leaching. The leaching was increasing from 45 kg per ha without fertilizer up to 110 kg per ha at an input of 110 kg per ha spread as ammonium-N in manure slurry in springtime.

Leaching and amount of fertilizer

When the amount of nitrogen fertilizer is increased (and other nutrients are plentiful) the yield will increase, and leaching will only increase slightly as long as the crop can take up the nitrogen. When the yield gets close to the optimum, leaching will start to increase considerably because plant uptake cannot follow suit. Fertilizers are left in the soil for possible leaching (see figure 2.5). It is therefore especially important to reduce over-fertilization, i.e. fertilization in excess of the optimum in terms of economy. Recent results from unconventional practices have, besides, shown that it is possible to reduce the input of fertilizers (and accordingly the leaching) below the economic optimum without any reduction in production or economic result worth mentioning (Esbjerg et al. 1990).

Autumn spreading of manure slurry results in large leaching losses (experiment B4). In the coarse sandy soil all ammonium nitrogen in the slurry spread in the autumn must be assumed to have been converted into nitrate and leached, as 110 kg N was added and 110 kg N leached. It must be noted that the winter under review was extremely mild offering favourable conditions for the mineralization.

Nitrate, which in the autumn is left in the soil, and nitrate, which during autumn and winter is formed as a consequence of mineralization, may to some degree be taken up, if the soil is covered by plants, as can be seen by a comparison of the results from experiments B3 and B5.

The two fields were treated similarly, except that there was a catch-crop (grass undersown in spring barley) in B5. This has in this case reduced leaching by approx. 15 kg N per ha. By keeping the soil covered by crop in the autumn, the risk of winter leaching may therefore be reduced.

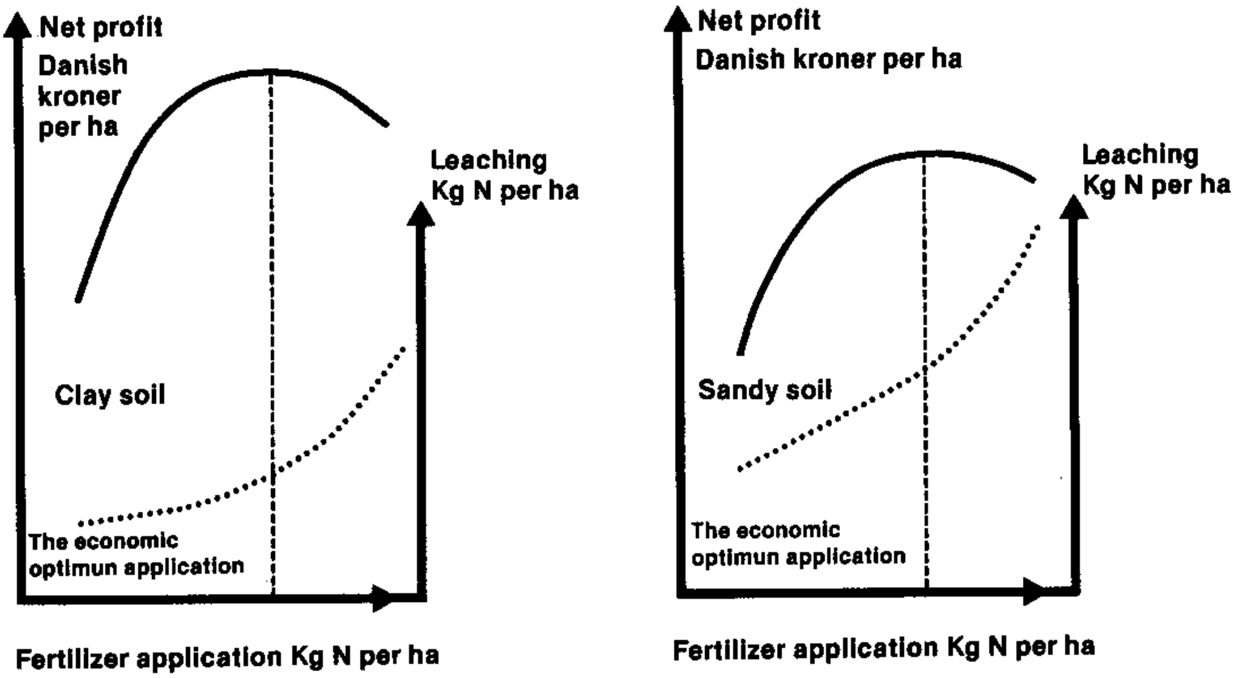

Figure 2.5 **Principle sketches of the effects of fertilization on the economic yield and on nitrogen leaching, from a clay soil and a sandy soil.**

Catch-crops

The amount of nitrogen which plants can take up during the autumn differs considerably, see table 2.2. In mild weather plants grow best and can therefore take up most by virtue of size and well-developed network of roots. As mild weather also increases mineralization, introduction of catch-crops is an efficient means to reduce leaching.

A winter crop sown early such as rape has time to absorb more nitrogen than the winter crops sown late in the autumn. A definite catch-crop sown with the sole purpose of taking up the nitrogen mineralized during autumn will have the largest effect if it can be undersown in spring cereals. Introduction of such late crops will, however, involve extra expenses for seeds and sowing, increased harvest trouble and problems in connection with the removal of straw.

	N-uptake kg N per ha
Winter barley, Oct-Dec	15-25
Winter wheat, Oct-Dec	10-20
Winter rape, Sept-Dec	15-55
Beet, Sept-Nov	60-70
Mustard after cereals, Sept-Dec	25-30
Rye grass, undersown in spring grain cereals, Aug-Dec	40-50

Table 2.2 **Nitrogen absorption in the autumn months by a number of different crops.** (Nygaard and Jensen 1988).

In connection with the above table, it is pointed out that the nitrogen absorption of winter crops in mild winters may be up to 50 kg N per ha (Olsen 1990).

Straw ploughing

If the organic matter to be mineralized is very poor in nitrogen (e.g. straw), the soil nitrogen may be retained in the soil microorganisms. Therefore, straw ploughing, if nitrogen is not at the same time added as fertilizer, may reduce the nitrogen leaching by 5-25 kg N per ha in the first year (Christensen & Schjønning 1987).

Nitrogen leaching from agriculture may thus in principle be reduced, even in case of large yields, if black fallow is avoided in the autumn, over-fertilization is prevented, and animal manure is spread in the spring when the risk of leaching is lowest.

A generalization of the leaching measurement, made by The Danish Research Service for Plant and Soil Science, to actual farming practices is difficult because practical farming often deviate considerably from the treatment of the experimental fields. Recently direct measurements have been made of the leaching during the period 1987-90 under actual farming practices (Hansen 1990c). As expected, a large variation was found in the average leaching from the individual crops – from 50 kg N per ha per year for winter cereals and grass treated with commercial fertilizers, to 80 kg per ha for winter cereals treated with animal manure and up to considerably more than 100 kg per ha for spring cereals and root crops. The leaching on an average was 93 and 79 kg total-N per ha per year for sandy and clay soils, respectively. These leachings were generally higher than the results optained from the experimental fields. One reason is that they include 10-15 kg N per ha as organic nitrogen, a contribution which is not measured in the experimental fields. Although the material is rather modest, it also indicates that fertilization in practice causes a somewhat higher leaching than the one measured under experimental conditions.

Similar results have been found in connection with the land monitoring programme, which monitor leaching of nutrients from farming areas. The monitoring programme comprises six watercourse catchment areas, which have been selected with a view to representing the soil types and the cultivating practices existing in Denmark. The first measurements of nitrate leaching for the calendar year 1989 from a total of 23 fields show an average leaching for sand soils of 78 kg N per ha per year and an average of 41 kg N per ha per year for clay soils. Organic nitrogen has not been measured. It is to be pointed out that, on account of remarkably low precipitation, percolation in the calendar year 1989 was considerably below mean.

Humus in the soil

The arable soil contains 5-10 tons nitrogen per ha in the organic matter – the humus. This amount will gradually change according to cultivation as it is generally assumed that animal manure and straw ploughing increases the amount of humus whereas repeated use of the same type of crop reduces it. No general assessments have been made of the change in the humus content of Danish arable soil. Long-term experiments near Askov over the past 30 years have shown falling humus content in the top soil, with respect to soil fertilized as well by commercial fertilizers as by animal manure and to soil where the straw has been ploughed in (Christensen 1988 and 1990). These results come from experimental fields and can therefore hardly be generalized to practical agricultural operations.

In general, there is great uncertainty as to whether the humus pool is increasing or decreasing with the present farming practices.

Calculations in the NPO Research Programme of fields under normal operation show that the use of animal manure and straw ploughing may increase the humus pool by up to 20 kg N per ha per year. By repeated cultivation of the same type of plants, a decrease in the order of 10 kg N per ha per year has been established (Johnsson 1990).

2.1.3. **Ammonia volatilization**

In connection with farming a steady admission of ammonia to the atmosphere takes place via volatilization from both plants and fertilizers.

Volatilization from plants

From plants with favourable growth conditions, a smaller ammonia volatilization may take place directly from the leaves – about 1 kg N per ha per year for barley (Schjørring & Byskov-Nielsen 1990). In previous studies (Schjørring et al. 1989), where the plants had poorer growth conditions, a loss of up to 40 kg N per ha has been estimated.

Volatilization from commercial fertilizers

No ammonia of importance volatilize from commercial fertilizers – nor from liquid ammonia. It adds up to only a few percentages of the total ammonia volatilization.

Volatilization from animal manure

Ammonia volatilization from animal manure takes place in connection with both the handling and storage of animal manure. Ammonia evaporates from the moment the manure leaves the animal until it has been ploughed into the soil.

The organic part of the fertilizer cannot volatilize, but ammonium is easily converted into the volatile gas ammonia, and at high wind velocity, heat, large surface, high pH and long deposit time, volatilization is increased.

Ammonia volatilization is largest in high-density livestock farming areas. This is reflected in figure 2.6, which shows a calculation of ammonia volatilization from animal manure per municipality, based on estimated standard values (Asman 1990). The municipalities with a high ammonia volatilization corresponds to the ones with high-density livestock farming areas.

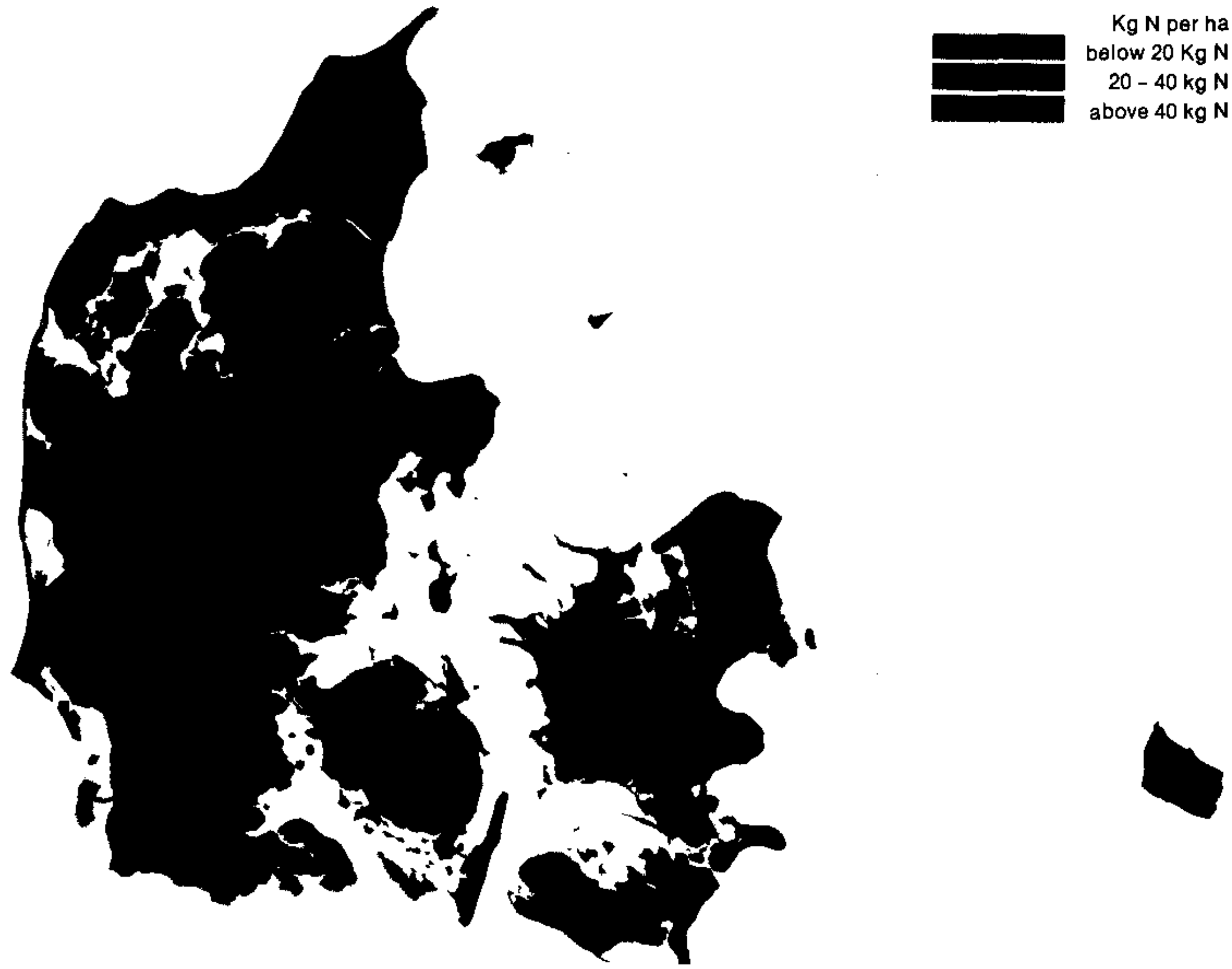

Figure 2.6

Calculated ammonia volatilization per municipality. Stated in kg NH_3-N per ha agricultural area (according to Asman 1990a).

Stable loss

There is some volatilization from stables as ammonia is led out with the exhaust air (Pedersen & Takai 1987). In different studies, the loss from stables is calculated to 2-20% of the total manure-N produced by the animals.

Storage loss

Storage of manure takes place as manure slurry or as solid manure and urine, seperatly. Manure slurry is kept in containers, solid manure in open dung yards with firm bottom and urine in closed containers.

Volatilization from slurry

Volatilization from an uncovered slurry surface may be relatively large and amount to up to 40% of the total nitrogen content in the container. If solid substances are present in manure slurry, they will, however, gather on the surface and form a natural, relatively dense, floating cover. Floating cover may, if required, be made artificially by the means of light clinkers or the like. From a manure slurry container which is covered by a natural floating cover, light clinkers or the like, less than 5% of the total nitrogen volatilizes (Sommer 1990a and National Agency of Environmental Protection 1990b), or about 8% of the ammonium content. Floating covers and similar covers may thus reduce the loss of ammonium by at least 80% compared with the loss from a container without floating cover.

Filling of the manure slurry container from below – by means of a submerged inlet – instead of filling from the top also reduces ammonia losses, see figure 2.7.

Volatilization from liquid manure

From liquid manure containers some nitrogen volatilizes through cracks and splits, because almost all the nitrogen is on the volatile ammonia/ammonium form. There is great uncertainty about how big this loss is, but it is estimated to be less than 5% of the total nitrogen content if the container is tight (Sommer 1990b). In case of very leaky containers, it is likely to be much bigger.

Volatilization from solid manure

From solid manure most of the nitrogen on ammonia/ammonium form is lost while the manure is deposited at the dung yard, mainly because it is added on top of old manure. The loss may be estimated to about one-fourth of total nitrogen content (National Agency of Environmental Protection 1984b). It is also possible that a certain loss of gaseous nitrogen occurs as a result of denitrification in the dung yard. This, however, remains to be studied.

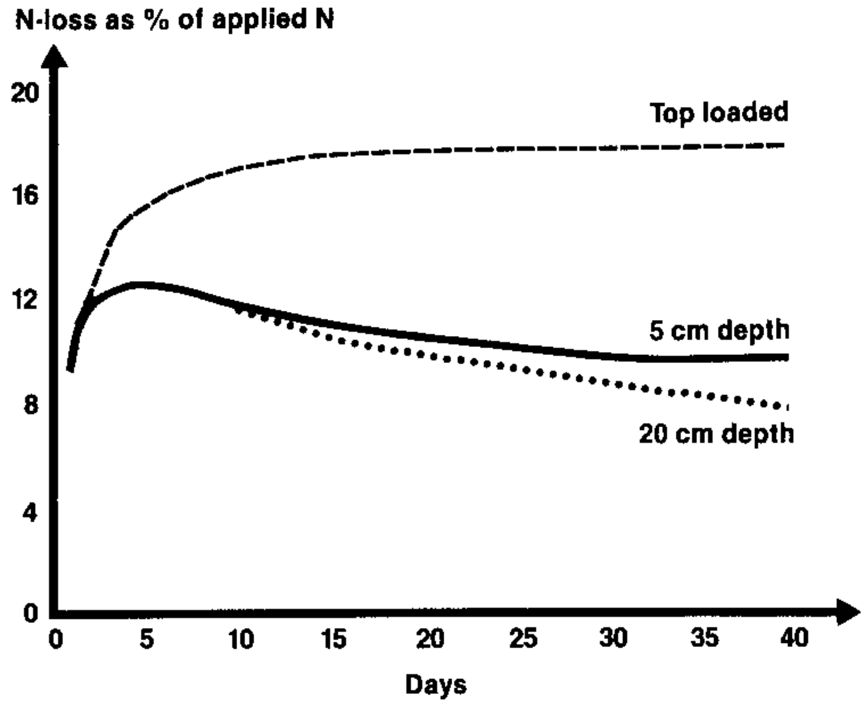

Figure 2.7 **The ammonia loss as function of filling depth and time. Each day 2 cm is added. The loss is expressed in percentage of the input of total nitrogen at any time** (Muck & Steenhuis 1982).

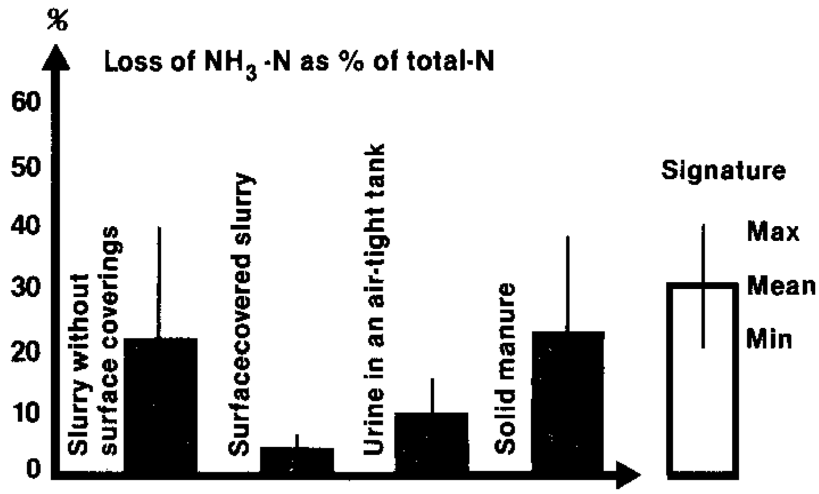

Figure 2.8 **The average ammonia volatilization from animal manure while in storage. The ammonia loss is expressed in percentage of total nitrogen content.**

Loss from spreading

Considerable losses may occur in connection with inadequate spreading of slurry. It is correct that in connection with the spreading of slurry as such, losses of only 1-4% of ammonium-N have been found.

Volatilization from slurry

From slurry lying above ground, however, the loss may be up to 60% of ammonium-N especially if the weather is hot or windy. If, however, the slurry is plowed down quickly, the loss may be reduced to less than 5% of the ammonium nitrogen (Sommer & Christensen 1990).

Volatilization from liquid manure

Urine easily penetrates the soil and the loss is estimated to be only 10-20% of the ammonium spread, even if it is not ploughed down (Sommer & Christensen 1990).

Volatilization from solid manure

It is calculated that from spreading of solid manure there is a loss of 20-40% of the ammonium spread (Sommer & Chistensen 1990). Since most nitrogen is fixed in organic form, the total loss is limited.

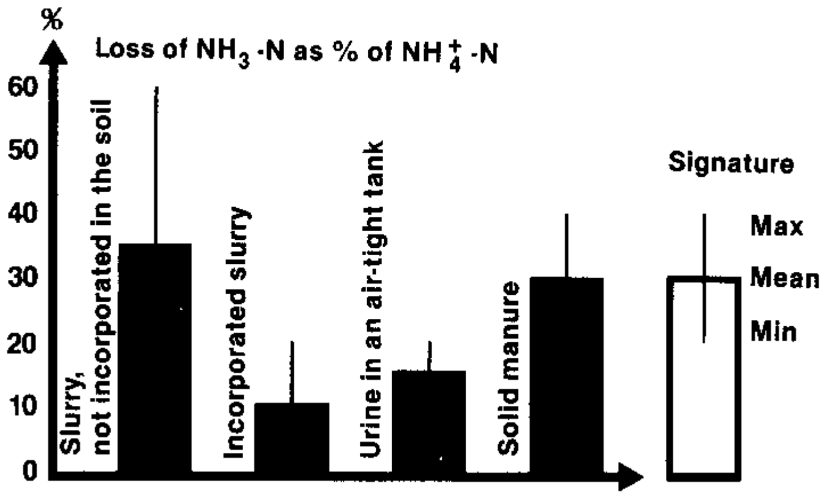

Figure 2.9

The average ammonium volatilization from animal manure at spreading. The loss of ammonia is expressed in percentage of the ammonium/ammonia content of the manure spread (Sommer & Christensen 1990).

2.1.4. Waste water from farms

The term »waste water from farms« comprises discharge of domestic waste water from the household of the farm and waste water from milking parlours and washing rooms. Also included are draining off of urine and liquids from stables and manure storages, respectively, and silage effluent from ensilage of green fodder such as grass and beet tops.

Before, waste water was discharged directly to drain or watercourse except in certain sand soil areas where it is normally percolated (Hansen & Sommer 1987).

The waste water has a high content of organic matter and nutrients such as nitrogen, phosphorus and potassium. The content of organic matter and ammonium means that the waste water has a large biological oxygen demand (BOD5), wherefore is has a heavy local impact on the aquatic environment.

2.1.5. **Denitrification**

Denitrification is a bacterial process where organic matter is oxidized under conditions deficient in oxygen, in that the oxygen content of the nitrate is used instead of free oxygen. By this, nitrate is converted into nitric oxide (N_2O) and further on to free nitrogen (N_2). Both gases escapes to the atmosphere.

Denitrification therefore requires the following three conditions fulfilled simultaneously: Nitrate, conditions deficient in oxygen and a labile carbon source (plant residue, animal manure, etc.).

Low denitrification in sandy soil

The denitrification is less in sand soils than in clay soils, because the sand soil's low water holding capacity means that the oxygen is not displaced from the soil pool.

Denitrification has proved to be low - not measurable - in coarse sand soils. In clay soils it shows considerable variation, depending on climate and management practices. According to the latest measurements on a sand-mixed clay soil near Askov it can be estimated to have been approximately 7 kg N per ha per year during the period 1987-89 (Lind et al. 1990). However, it cannot be excluded that in some years - especially in the spring - a short-term, but very high denitrification occurs in case of optimum conditions. (Maag 1989).

In wetlands with input of nitrogenous water, as e.g. undrained meadows, very high denitrification rates of up to 400 kg N/ha a year have been found (Brusch 1990). There seems to be a potential for nitrate removal, if the area with undrained meadows is extended so that the full denitrification potential can be exploited.

2.1.6. **Input, conversion and transport of phosphorus**

Decomposition of phosphorus

Phosphorus is found in the soil, partly in organic matter, partly in inorganic matter as phosphates. The organic matter will mineralize and liberate phosphates which can be taken up by plants. Not all phosphate forms, however, are equally accessible to plants. In well-oxidized soil, as ordinary cultivated soil, phosphates are almost insoluble. The inaccessible forms, i.e. the insoluble forms, will be retained in the soil and the leaching is, therefore, much smaller as for water-soluble nitrate.

Arable land is fertilized by animal manure where part of the phosphorus is on organic form, and by commercial fertilizers where the phosphorus is found as easily accessible phosphates. The value of phosphorus in animal manure is almost the same as in commercial fertilizers.

On average, 1,800 kg phosphorus per ha is found in the top soil in Danish arable land. About half is on organic form, the remaining half being inorganic.

	Total kg P per ha per year
Applied as animal manures	17,5
Applied as fertilizers	16,4
Applied as deposition	0,2
Applied as sludge	0,7
Total application	34,8
Removed through harvest	22,0
Removed by leaching	0,3
Total removed	22,3
Net-application to soils	12,5

Table 2.3

Phosphorus balance for one ha of arable soil (National Agency of Environmental Protection 1988).

It can be concluded from the table that about one third of the phosphorus added to arable soil is accumulated.

Phosphorus fertilizing

Phosphorus fertilization of the individual fields varies much, 5% of the fields receive no P-fertilizer, and 5% get 125 kg P per ha per year as appears from figure 2.10. Especially fields fertilized with animal manure receive much phosphorus by way of both commercial fertilizers and animal manure. The explanation must be that the value of animal manure is fixed according to the amount of nitrogen in the manure (Hansen 1990) which may imply an apparent over-fertilization with phosphorus in the year concerned. As phosphorus is fixed effectively in the soil, the surplus amount of phosphorus can, however, be used the following years.

2.1.7. Loss of phosphorus from arable soil

Phosphorus leaching

Leaching from agriculture's mineral soils has previously been calculated to about 0.3 kg total phosphorus per year per ha (Table 2.3). Recent studies, however, show figures which are a little higher. In 10 fields with different types of soil, crops and use of animal manure, the leaching varied from 0.6 to 1.3 kg total phosphorus per ha per year, hereof 0.1 to 0.2 kg phosphate-phosphorus per ha per year. (Hansen 1990b). Leaching of organic phosphorus is an important part of the total phosphorus leaching. It must be pointed out, however, that there are considerable difficulties connected to the methods of obtaining a precise determination of the organic phosphorus leaching.

Leaching from peat soil may be higher than from ordinary mineral soils.

The phosphorus concentration in soil water in depth of one meter varies from 0.1 to 2 mg per litre depending on type of soil, crop and time of year (Hansen 1990b).

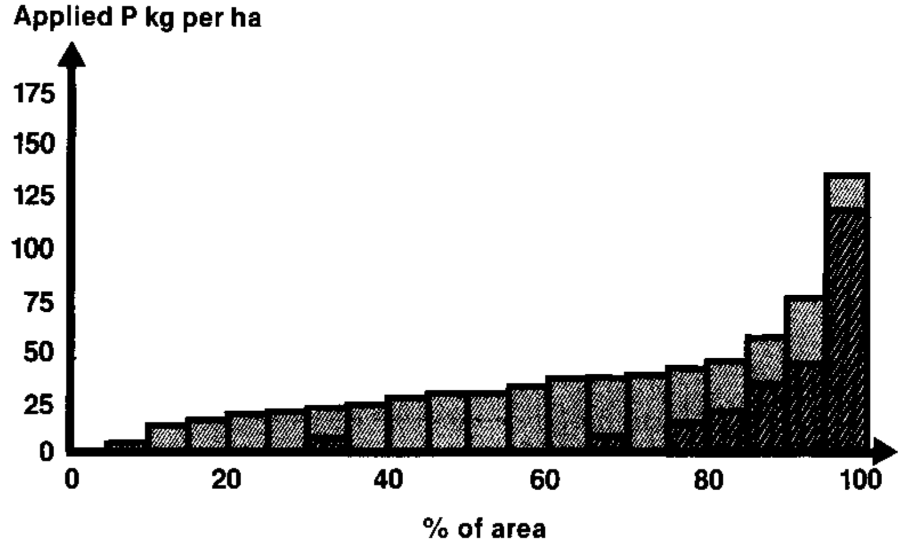

Figure 2.10

Input of phosphorus to fields in two watercourse catchment areas, Rabis stream near Viborg, Jutland and Syv stream near Roskilde, Zealand. The hatched part of the columns shows phosphorus in animal manure.

The eutrofication of watercourses and lakes may – in addition to drainage – take place by surface soil-, brink- or wind erosion. An investigation carried out in 1988-89-90 showed no wind erosion of significance.

Phosphorus erosion

During the same period, surface erosion was modest. The highest measured value was 0.05 kg P per ha per year measured on a clay soil with a 12% slope (Hasholt et al. 1990). Sand soils and clay soils with smaller slope are estimated to have even smaller erosion. It should, however, be added that the largest risk of erosion is deemed to be at heavy thaw after the soil has been frozen. Such weather conditions have not occurred during the experiment period. It is calculated that 3% of Denmark's area is threatened by erosion.

Brink erosion may locally contribute somewhat to the phosphorus supply of watercourses, as arable soil, as mentioned before, has a large content of phosphorus.

2.2. Sewage Treatment Plants

The major part of Denmark's population, approximately 93%, are connected to a sewer system, and the main part of the waste water is thus carried via treatment plants to fresh and marine waters.

Types of waste water

In addition to domestic waste water, industrial waste water is led into the waste water plants. On a national level this amounts to as much as the domestic waste water. The amount of waste water is normally expressed in person equivalents (PE), i.e. the amount of waste water which one person produces.

By 1 PE is understood 21.6 kg organic matter per year measured as BOD5, 4.4 kg total nitrogen per year or 1.5 kg total phosphorus per year. BOD5 means biochemical oxygen demanded after five days and nights.

Only an insignificant part of the total waste water amount is discharged without any treatment.

Throughout the years, there has been a clear tendency to gather waste water treatment in fewer and bigger treatment plants.

Number of plants

Thus, in 1983/84, (National Agency of Environmental Protection 1984b) 2,244 municipal treatment plants were registered, which number in 1989 had been reduced to 1,618 plants.

The number is expected to fall further to approximately 1,300 during the next 5-10 years.

To this is added a number of private treatment plants for domestic waste water. In 1983/84 these were not registered.

In 1989, 357 private plants larger than 30 PE were registered. The number is expected to fall to approx. 300 in 5-10 years.

The private treatment plants are primarily small mechanical treatment plants, and the amount of waste water led to these plants is only 0.9 per cent (1989) of the total amount of waste water.

Treatment of the total volume of waste water in 1983/84 and 1989, respectively, appears from table 2.4.

Treatment measures

Mechanical treatment works by sedimentation of suspended matter which is then removed as sludge. By this treatment method, 20-40% of the contents of the waste water of BOD5 can be expected to be removed and 10-20% of N and P, according to the composition of the waste water. The biological treatment takes place by means of microorganisms. By this treatment up to 85-95% of the organic matter is removed and 20-40% of N and P.

Treatment plant	% of the total amount of waste water 1983/84	1989	Number of plants 1989
Without treatment	10	1	13
Mechanical	20	14	981
Mechanical-biological	67	59	764
Mechanical-chemical	0,5	6	30
Mechanical-biological-chemical	2	8	120
Mechanical-biological supplied with removal of nitrogen	0,5	2	8
Mechanical-biological-chemical with removal of nitrogen	0	10	59
Total	100	100	1975

Table 2.4 **Treatment measures in municipal and private waste water treatment plants over 30 PE.**

Chemical treatment is especially directed towards removal of P, and takes place by precipitation with lime, iron or aluminium salts. 80-97% of P may be removed in this way.

Removal of nitrogen is a further biological process. First, the content of ammonia and organic nitrogen in the waste water is converted into nitrate, which process takes place by the presence of oxygen (nitrification). Next, nitrate nitrogen is converted to gaseous nitrogen under oxygen-free conditions (denitrification). The removal of nitrogen is 85-95%.

The purification methods may be combined and integrated in different ways.

In addition to waste water in areas with sewage systems, waste water appears from sparsely built-up areas and villages and summer cottage areas which have no sewage systems.

2.3. Outlets conditioned by rainwater

Two types of discharge

There are two main types of discharge of surface run-off from consolidated areals – discharges from areas with separate sewage systems, where rainwater is discharged separately in own main system direct to recipients, and discharges from areas with common sewage systems where rainwater is discharged in the same mains system as other waste water. Discharges then take place through overflow structures and are mixed with other waste water.

The total area with sewage systems in Denmark is 227,000 ha. Approximately 43% with common sewage systems and the remaining 57% with separate sewage systems.

At the beginning of the 1980s, the total area with sewage systems was estimated to be 180,000 ha, distributed by 45% with common systems and 55% with separate systems (National Agency of Environmental Protection 1984b). (Tabel 2.5).

In 1989, approximately 4,800 overflow structures and approximately 7,300 discharges for separate surface water were registered.

Purification measures

For a number of years it has been common practice to request the establishment of treatment measures for both types of rainwater dependent outlets, but there are, however, still outlets without such measures.

In outlets for separate surface water, a grit chamber and oil separator, and in some cases basin, are usually required. The purpose of the basin is partly to neutralize the hydraulic load which may indirectly lead to pollution of the recipient by erosion, partly to clean the water before discharge by simple sedimentation.

Overflow structures usually require a grate and in some cases basin. The purpose of the basin is to store the water, which would otherwise be unloaded, until, after termination of rainfall, there is again capacity in the sewage system. Basins are rarely established with a capacity for storing the volume of water of all rainfall occurrences. Therefore, there will still be a certain discharge from the overflow structure.

If the design of the system is adequate, the discharged water will, however, have been subjected to a sedimentation in the basin and thereby it becomes diluted to a considerable degree.

Approximately 20% of the discharge from separate systems takes place via a basin.

For overflow strucures too, it is about 20% of the consolidated area (the area contributing to the discharge) which has got basins.

Sewersystem	Number of outlets/ overflows	Total area (1000 ha)	Consolidated area (1000 ha)
Common without basin	4.070	78	25
Common with basin	715	21	6
Common total	4.785	99	31
Separate without basin	6.353	102	28
Separate with basin	941	27	8
Separate total	7.294	129	36

Table 2.5 **Number of outlets/overflows and areas for common systems and separate systems.**

Note: The distribution of areas on plants with/without basins are estimated by the National Agency of Environmental Protection for the City of Copenhagen and the counties Frederiksborg, Bornholm, Funen and North Jutland.

A survey of what is discharged via the rainwater dependent outlets requires complex calculations in which many parameters are included.

One of most important parameters is the size of the area contributing to the run-off. Besides, in case of common systems, it is necessary to know the water volume (rainwater and waste water) carried to treatment plants, and last, but not least, the amount of precipitation and its extent in terms of time is of great importance.

Several models have been developed to calculate the discharge, ranging from simple estimates to advanced computer calculations.

In connection with the survey in 1989, simple calculations have primarily been used.

Thus, what approximately 90% is concerned, the discharge in 1989 is based on assumptions taken from the municipal waste water plans, and the calculation are made on the basis of assumed unit figures for the discharged amount of water and substance per area unit. The remaining part is calculated on the basis of more detailed assumptions, such as measuring on maps, and the calculations are most often made by computer models.

The unit figures which, with a few exceptions, have been used appears from table 2.6.

The amount of precipitation is the all-important factor in relation to the size of the discharge. As precipitation and its distribution, however, vary much from one year to another, the amount of precipitation for one particular year has not been used in the calculations. Instead, a series of precipitation measurements throughout a period of 33 years has been applied, know as the »Odense-series«.

The discharges thus calculated does not apply to the year 1989, but to a »normal year«.

The results of the calculation are shown in section 4.3.

The survey of the discharge from outlets dependent on rainwater is subject to a considerably larger uncertainty than e.g. the survey of the discharge from treatment plants.

Attempts will be made during the coming years to minimize this uncertainty based, among other things, on the experience to be gained in connection with an intensive gauging programme on a number of selected outlets dependent on rainwater.

Common systems		The unit figures per reduced ha per year		
Outlet figures (μm/S)	Volume of basin (mm)	Water m^3	Total-N kg	Total-P kg
0,1	0	2.317	29	7,7
	2	1.424	18	4,7
	10	299	3,6	0,95
0,3	0	1.434	17	4,4
	2	706	8,0	2,1
	10	137	1,5	0,39
1,0	0	466	5,0	1,3
	2	220	2,3	0,59
	10	49	0,51	0,13
Separate systems		3.800	7,6	1,9

Table 2.6 **Area unit figures of discharge from outlets dependent on rainwater.**

2.4. **Industry**

Waste water from industry

Waste water of different kinds and different degrees of pollution are discharged from industries, as e.g. processing waste water, cooling water, cleaning water, sanitary waste water and surface water.

Most industries discharge waste water to the local waste water treatment plants, but some industries treat their own waste water and discharge it directly to fresh and marine waters.

100 industrial enterprises have been registered, from which waste water is discharged, with a certain content of pollutants, directly to watercourses, lakes or the sea. In this survey, discharges of less than 30 PE are not included; i.e. cooling water discharges and smaller discharges of sanitary waste water, etc.

Besides, there are 62 industrial enterprises whose waste water is sprayed on farm land. Very few industrial enterprises have percolation plants.

Special discharges

To this are added discharges of urea used for thawing of road bridges and airports.

In the sections on industry in this report, only the separate discharges are discussed, whereas industrial discharges to the local sewage plants are dealt with under the section dealing with discharges from municipal waste water treatment plants. Under separate discharges are included discharges through the local mains after the local waste water treatment plant.

Separate discharges

As a consequence of the Action Plan for the Aquatic Environment, requirements are made for larger separate discharges of nitrogen and phosphorus – all industrial enterprises which on an annual basis discharge more than 66 tons of nitrogen or 7.5 tons of phosphorus are required to reduce the discharges by means of the best available technology.

In addition discharges from smaller enterprises, which are regulated out of regard to local recipient quality may, according to decision by the county councils, be comprised by the same requirements.

2.5. Aquaculture

The most important aquaculture plants, as far as the Action Plan for the Aquatic Environment is concerned, are freshwater fish farms, marine aquacultures and salt-water fish farms.

Fish farms

Fish farming has developed in Denmark over the past 100 years when spawn of rainbow trout was imported from the United States. However, production and number of fish farms increased only slowly. But in the 1950s progress was eventually made, and in the middle of the 1960s, the main part of the present Danish fresh water fish farms had been built. By the end of 1989, there were 509 Danish freshwater fish farms of which the 483 were in operation. Practically all of them are located near watercourses where they use the water of the watercourse for operation.

In 1977, annual production was about 15,000 tons (Markmann, 1977), in 1985 about 25,000 tons (Hørlyck, 1985), and in 1988 and 1989 it was 29,000 and 34,000 tons, respectively.

Traditionally, the plants are designed as ground ponds, but lately, however, some plants have been built with cast concrete ponds. The most recent types of plants have circular containers made of iron or fibreglass-reinforced plastic.

Over the past 10-20 years, pollution from fish farms has caused considerable problems in watercourses and lakes. Results in controlling this pollution has only been obtained to some extent, and therefore method and product developments are still furthered, including production of better types of feed and more effective mechanical cleaning systems.

The pollution originates partly from feed waste, partly from the metabolic products from the fish secreted through the gills and with excrements and urine. The solid elements from feed waste and fish excrements are separated as far as possible, e.g. by sedimentation. The better the separation works, the smaller the watercourse pollution.

Improvements of the purely mechanical cleaning methods may thus have an effect on the discharge of solid substances. The amount of dissolved pollutants can, however, only be reduced by improving feed quality and feeding.

Marine aquaculture and salt water fish farms

Marine aquaculture farm operations have developed in Denmark over the past 10-15 years. In 1978, production was less than 100 tons on five plants. By the end of 1986, there were 35 plants with a total production of 2,800 tons. The 1989 production was 4,700 tons.

The pollution problems in relation to marine aquaculture farms and saltwater fish farms are the same as for freshwater fish farms. However, it is not possible in marine aquaculture farms to separate feed waste and excrements. The only way to reduce pollution is by improving feed quality and feeding techniques.

2.6. **Energy and Traffic**

Emission

By combustion of coal, oil and natural gas an oxidation takes place, partly of the nitrogen which might be in the fuel, partly of the nitrogen which is in the combustion air. As coal contains more nitrogen than e.g. oil, combustion of coal will result in larger emissions of nitrogen oxides, NO_x, than combustion of oil.

Emission of NO_x from combustion processes also depends on combustion temperature, i.e. the higher the temperature of combustion the more oxidized nitrogen, and the more NO_x is emitted.

This means that coal burning power plants operating at relatively high temperatures, approx. 1,500° C, and combustion engines working at very high temperatures, approx. 2,500 °C, emit large amounts of NO_x compared to the fuel consumption.

Emission of nitrogen oxides, NO_x, takes place as a mixture of nitrogen monoxide, NO, and nitrogen dioxide, NO_2, with increasing weight on NO at the outlet of chimney or exhaust pipe. In the atmosphere NO is gradually oxidized to NO_2, which again takes part in a great number of chemical processes, which e.g. generate salts of nitric acid or other nitrate compounds.

NO, as well as NO_2 and the nitrates, can be deposited directly on land and water surfaces or can be washed out from the atmosphere as nitrate compounds via precipitation and thereby being carried to land or sea areas.

The latest official Danish emission survey of nitrogen oxides dates from 1988 and shows an emission, converted to pure nitrogen, of approx. 76,000 tons. The emission related to the main sources are shown in table 2.7.

Power plants	38.400	tonnes	51%
District heating plants	2.200	tonnes	3%
Industry	5.700	tonnes	8%
Individuel heating	2.200	tonnes	3%
Transport, domestic	27.100	tonnes	36%
Total	75.000	tonnes	

Table 2.7 **Emission of oxidized nitrogen, NO_x, in 1988, distributed on the main sources.**

Emissions from industry are calculated solely on the basis of fuel consumption as the emission from processing plants, primarily production of artificial fertilizers is marginal and less than 300 tons nitrogen a year.

The transport sector comprises road transport, railways and domestic shipping and air traffic. Road traffic is responsible for by far the largest emissions, i.e. 24,900 tons.

The distribution of ammonia emission on sources is indicated in section 4.1.2.

2.7. **Deposition of nitrogen from the atmosphere**

NH_x and NO_x

The atmosphere contains (in addition to the natural nitrogen content) several nitrogen compounds on gaseous form, dissolved in water drops or absorbed on particles. Some nitrogen compounds (reduced nitrogen or NH_x) originate from volatilization from animal manure while others (oxidized nitrogen or NO_x) originate from combustion in industry, power stations and transportation. Considerable parts of these compounds originate from sources outside Denmark.

On land as well as on sea areas, these nitrogen compounds are deposited from the atmosphere. The nitrogen is deposited with rainwater as wet deposition or as dry deposition by direct contact with the surface.

2.7.1. **Wet deposition**

The content of NO_x and NH_x in precipitation is measured in samples collected in permanently open funnels. Therefore some dry deposited nitrogen in particle and in gaseous form is collected together with the content of precipitation of NO_3- and NH_4^+ (wet deposition).

Bulk deposition

This sort of determination is called bulk deposition, and the method is estimated to give a result which is 0-30% higher than the actual wet deposition, depending on the location of the measuring instrument in relation to nearby ammonia sources.

Measurements of the annual bulk deposition in the late 1980s shows that it was about 14 kg N per ha as an annual average on a national basis (Grundahl and Hansen, 1990), with about 8 kg NH_x -N per ha and a little less than 6 kg NO_x -N per ha. A doubling of the level has been found as compared to the 1950s, where it was about 7 kg N per ha. Compared to the level in the 1970s - 12 kg N per ha – it was, however, a minor increase so that the deposition may on the whole be considered stabilized in the 1980s.

A clear regional difference has been established in the deposition, with the highest level in Mid, West and South Jutland, 16-17 kg N per ha, and the lowest in Zealand, about 10 kg N per ha. No change of the level has been found in Zealand since the 1970s.

The increase in the deposition of nitrogen with precipitation since the 1970s in the Jutland monitoring stations is most likely due to a combination of precipitation and increased ammonia volatilization from increasing animal husbandry.

2.7.2. **Dry deposition**

Dry deposition of nitrogen compounds is extremely difficult to determine by means of measuring. The dry deposition can only be measured with great uncertainty, and it is in practice determined by calculations based on air concentrations.

Studies have shown (Sommer 1990a) that around the emission sources, dung heaps, stables and fields with application of manure, there is a considerable dry deposition of ammonia-nitrogen.

It can be estimated that in areas with intensive animal husbandry, dry deposition is about 10-15 kg N per ha, whereas, in areas without animal husbandry, it is about 1-2 kg N per ha. On average nationally, a level of about 7 kg N per ha has been found.

Dry deposition of NO_x and nitrate compounds are, in this connection, considered insignificant.

2.7.3. **Total nitrogen deposition**

Land areas

Total average deposition of nitrogen from the atmosphere can be estimated to about 21 kg per ha per year, varying between about 12 and about 30 kg per ha per year, depending of amount of precipitation and animal husbandry in the region. The distribution between the different elements appears from table 2.8.

	Kg N per ha per year
NH_x Wet deposition	8
NH_x Dry deposition	7
NO_x Wet deposition	6
NO_x Dry deposition	0
Total	21

Table 2.8 **Average deposition of nitrogen from the atmosphere in Danish agricultural areas.**

These measurement results are supported by model calculations carried out by a working group under the ECE Convention on transborder air pollution, European Monitoring and Evaluation Programme (EMEP). This programme deals with emission, transportation and deposition of air pollution in Europe. The basic data used to map emission is the national surveys, whereas the transportation and deposition calculations are made solely by means of over more advanced models. The EMEP-calculations show a total nitrogen deposition on Danish land areas of 20,2 kg N per ha in 1988 (Iversen 1990).

Regional distribution

The regional distribution of the average NH_x-deposition on agricultural areas in the individual municipalities has been calculated as shown in figure 2.11.

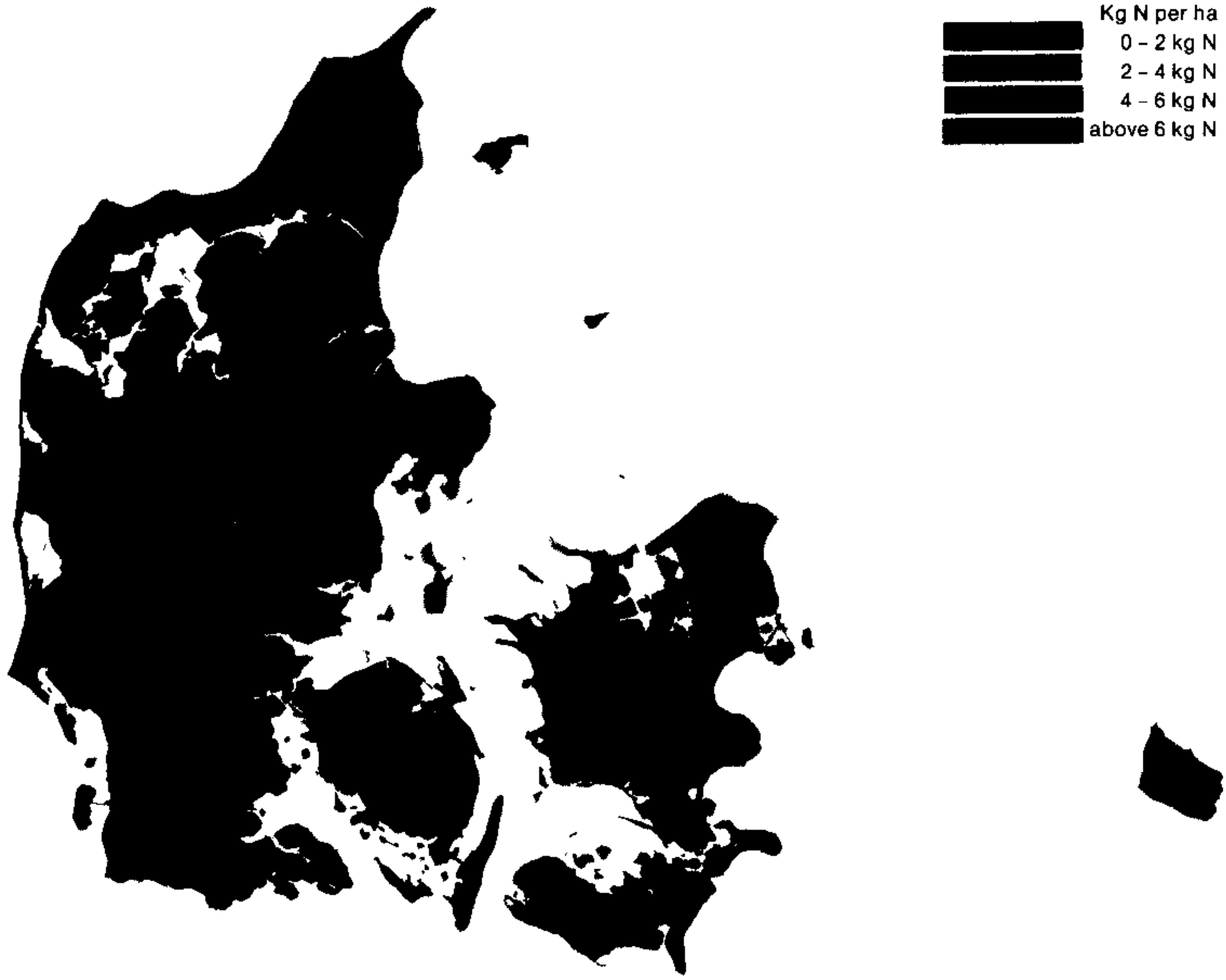

Figure 2.11 **Calculated municipal distribution of ammonia deposition. Stated in kg NH_x-N per ha (according to Asman 1990).**

The deposition is high in high-density livestock farming areas, but due to the atmospheric transportation large deposition is also seen in other areas. No similar calculations have been made for NO_x, but the regional distribution is assumed to be considerably more uniform.

Natural areas

In natural areas, far from emissions from agriculture, the deposition of nitrogen from the atmosphere in 1989 is estimated to about 10 kg N per ha (Hovmand 1990).

Marine areas

The annual deposition over marine areas is found to be about 11 kg N per ha for 1989 (Hovmand 1990).

In the EMEP-calculations, no calculations have been made for Danish marine waters. But based on of the report, it can for the Kattegat be estimated that the deposition is about 6 kg N per ha for oxidized nitrogen and 7 kg N per ha for ammonia-nitrogen, corresponding to a total nitrogen deposition of about 13 kg N per ha. As the velocity of deposition for certain compounds of oxidized nitrogen is lower over water than assumed in the calculations, the estimate must be considered to be too high. A deposition of about 10 kg N per ha in marine areas must therefore be considered to be a realistic estimate.

3. Effects on the aquatic environment of increased input of nutrients

The various sources of input of nutrients are part of a complicated transport and transformation system in the aquatic environment, as outlined in figure 3.1.

An increase of input from the sources results in a corresponding change in the aquatic environment. In ground water the quality is deteriorated, and in freshwater and marine areas there is an increase in both nitrogen and phosphorus concentrations.

Agriculture's losses go to the atmosphere, ground water and to streams and lakes. The discharges to streams and lakes are augmented by the waste water discharges before being transported to nearshore waters and further on into open sea. On the route, however, a considerable transformation and in many cases direct removal takes place, in particular of nitrogen.

An excessive load of nutrients in freshwater and marine water areas results in increased production of organic matter, known as eutrophication, with increased production of algae, turbid water, oxygen depletion and fish mortality as consequenses. However, the actual effect of the increases is strongly dependent on the nature of the waters, and on biological and climatic conditions. The conditions of the aquatic environment consequently show great variations as function of load, climate, etc.

In Chapter 3, these conditions are illustrated for ground waters, watercourses, lakes and marine areas.

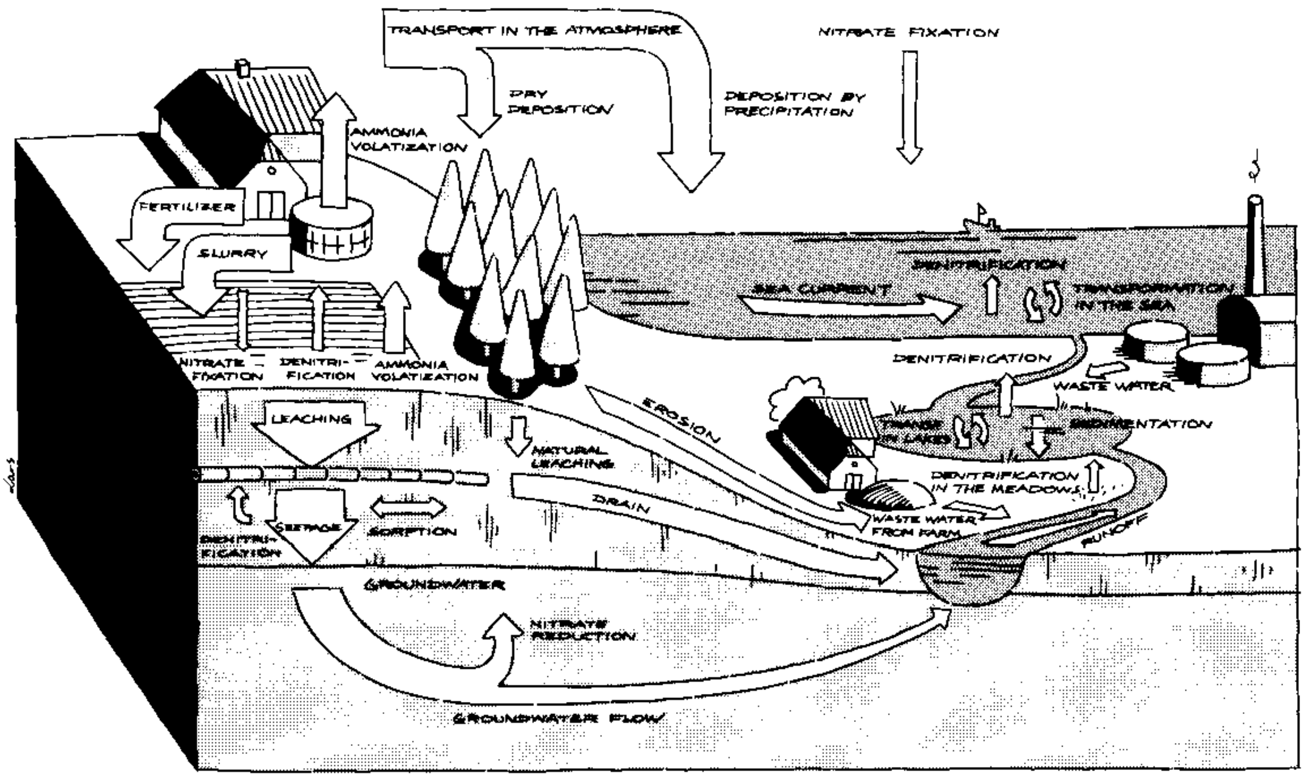

Figure 3.1 **The nitrogen cycle.**

3.1. Ground water

The Danish drinking water supply is almost solely based on abstraction of ground water. Ground water represents at the same time the most important contribution to fresh surface recipients.

Therefore, the quality of ground water is of decisive importance for both drinking water quality and the water quality in lakes, watercourses, etc.

Effects of intake of nitrate

In spite of nitrate being an essential nutrient for animals and plants, and thereby for human beings, there is a well-documented connection between intake of larger amounts of nitrate and development of infant methaemoglobinanemia (reduction of blood's ability to fix oxygen). Scientific studies in recent years have raised suspicion as to the cause-effect relationship between the transformation products of nitrate formed in the body and development of stomach cancer and certain occurrences of teratogenicity. (The Minister for Health 1990). The concentration limits of nitrate in drinking water must be seen in connection with the nitrate intake from other sources.

Phosphorus is not an actual health hazard, but may indirectly damage the water quality by, together with nitrate and organic matter, causing bacterial growth in the water mains system (National Agency of Environmental Protection 1984b).

Flow of ground water

Ground water is formed from rainwater percolating through the aquifers until it reaches a ground water reservoir. From here either run-off takes place to fresh or marine waters or the ground water is utilized for water supply purposes. Part of the rainwater may continue to deeper ground water reservoirs, from where run-off may again take place to the fresh and marine waters or pumping up for water supply purposes may be carried out.

3.1.1. Ground water formation

Percolation of rainwater from the surface to the lower ground water reservoirs may, depending on local geological conditions, last for a period of a few years up to hundred years or more. Abstraction for water supply purposes from deep borings may thus be based on very old rainwater and is thereby largely unaffected by man-made contamination.

On the other hand, the deepest ground water reservoirs often have a naturally poor water quality, either making the water unfit for water supply purposes or requiring a extensive and costly water treatment at the waterworks.

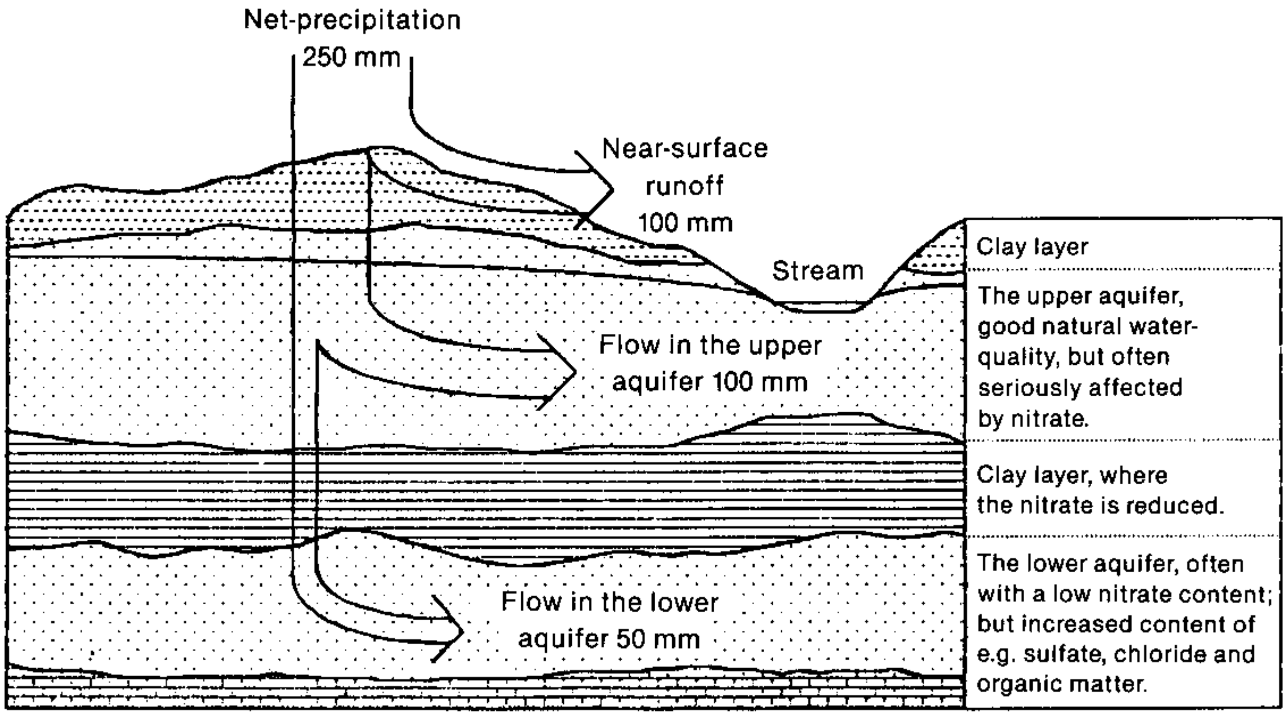

Figure 3.2 **Interrelationship between net precipitation, run-off, ground water formation and water quality in various ground water aquifers.**

3.1.2. Nitrogen in ground water

Nitrate in newly-formed ground water

Ground water which is formed today is strongly affected by nitrate. Recent research has shown that the nitrate content in water leaving the root zone under agricultural areas considerably exceeds the limit volume given for drinking water, the guide level is 25 mg nitrate per litre and the admissible content is 50 mg nitrate per litre), with concentrations from 50 – 400 mg nitrate pr litre (corresponding to 11-90 mg nitrate-N per litre) (B. Hansen 1990b).

The nitrogenous water will either, through run-off, be carried to watercourses, lakes or the sea, or it will slowly percolate to ground water reservoirs, thereby to an increasing degree be determining for the quality of the available ground water resource and for the water quality in fresh and marine waters.

Nitrate reduction in aquifers

In some areas the effect on the ground water quality is reduced as a result of a natural reduction process in the aquifers where nitrate is converted into free nitrogen. This denitrification is one of the reasons why even a considerable load of nitrate in the percolated water only to a limited extent results in serious effects on the deeper ground water reservoirs.

The natural nitrate reduction is important in two areas especially:

- where the aquifers are characterized by considerable clay occurrences (e.g. in Zealand), a decomposition of nitrate to free nitrogen by a reaction with grit-fixed iron takes place. (Ernstsen et al. 1990).

- in distinct sandy areas with high content of organic matter and the iron compound pyrite (e.g. parts of west Jutland), the conversion of nitrite to free nitrogen will be conditioned by chemical and microbiological reactions with deposits of pyrite and organic matter (Postma and Boesen 1990).

Effect of nitrate reduction

In practice, however, it is not in all parts of the general geological environment mentioned that the conditions for a larger nitrate reduction exist. For example, the strata of clay and the pyrite deposits will not always be homogeneously distributed. Pyrite occur sporadically and clay strata are often characterized by fissures and are cut through by sand schlieren. Generally, clay strata on a large scale are more widespread in Zealand and Funen than in Jutland.

It should be mentioned at the same time that the nitrate reducing capacity of aquifers is an absolute quantity. A considerable and continuous nitrate load may therefore in the long term have as consequence that the effect of the natural reduction process is reduced or that it ceases completely.

The importance of ground water withdrawal

It is, moreover, important to distinguish between ground water flowing naturally and ground water influenced by water abstraction. Abstraction of ground water may often change the directions of flow in an area radically, resulting in contaminated water being drawn into the abstraction boring. A ground water reservoir, which is »undisturbed«, may thus contain water of good quality, whereas the changed conditions of flow in connection with abstraction may result in contaminated water being drawn down from upper levels or water with a naturally poor quality may be pulled up from deeper reservoirs. A ground water reservoir, which are estimated as well-protected, with a very high degree of natural nitrate reduction compared with the depth of the drilling's intake of water, may therefore anyway cause quality problems in the water supply (see figure 3.2).

The effect described («sinking cone«) is considered to be of great importance under Danish geological conditions and it is, therefore, not always possible to obtain permanent quality improvements in the water supply through deeper borings.

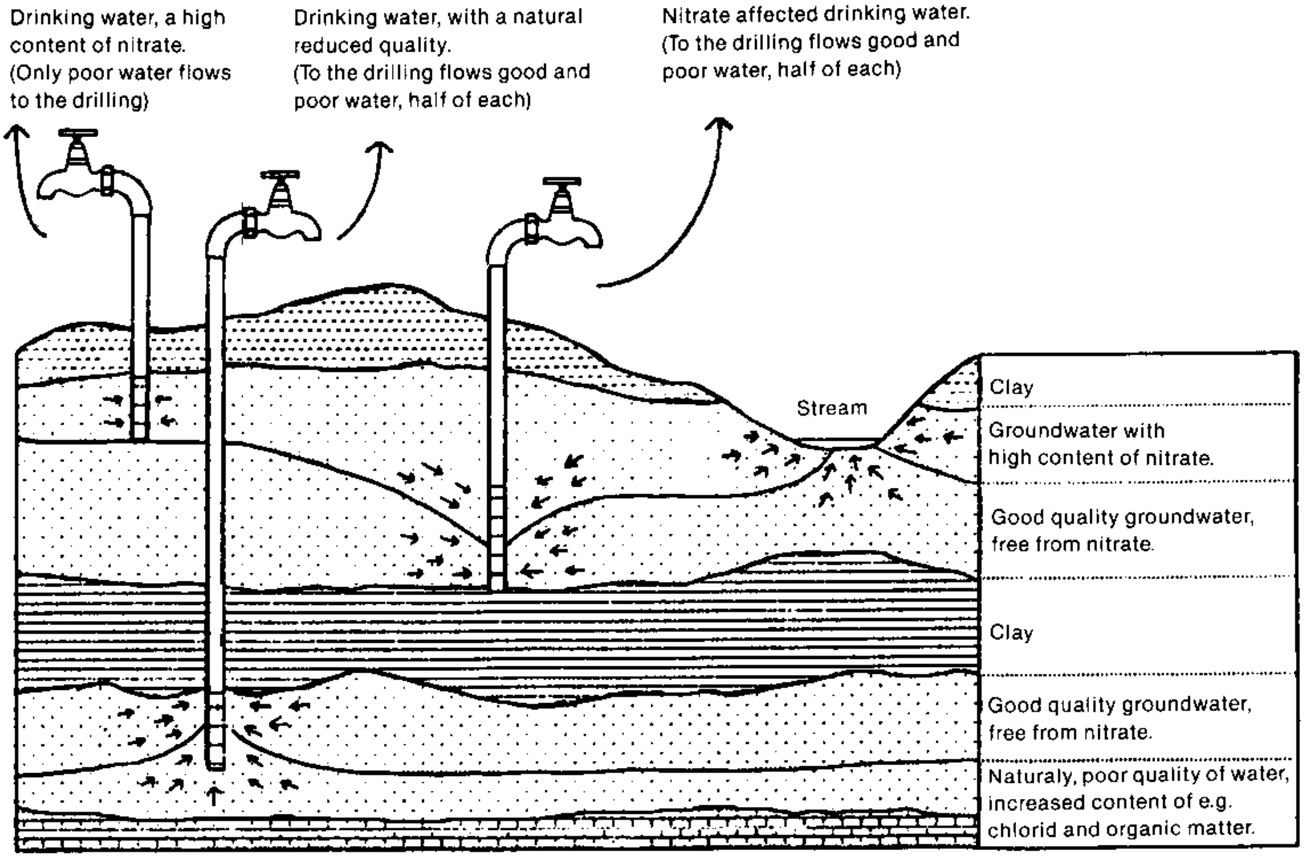

Figure 3.3 **Interrelation between water abstraction and ground water quality in different reservoirs. It is noted that the water abstraction draws the nitrate front downwards.**

Undesired consequences of nitrate reduction

Formation of sulphate and iron by a reaction between nitrate and pyrite may be a serious limitation to the improvement of the ground water quality, obtained through nitrate reduction, since the volume of these »by-products« may be so large that it becomes difficult to use the ground water for water supply purposes. The extent of sulphate formation may be illustrated by the fact that for each mg reduced nitrate, 1 mg of sulphate is formed, followed by an acidification of the ground water (Postman & Boesen 1990). Run-off of acid and ferroginous ground water might lead to a deterioration of the quality of watercourses, as a result of reductions of the pH of the watercourses and precipitation of ochre.

Extent of nitrate pollution

It is, at this present moment, difficult to give an unambiguous status of the actual nitrate pollution of the different ground water reservoirs. On the basis of information available, it must, however, be assumed that the nitrate pollution of ground water today is on a scale which means that a great part of the upper and few of the deeper reservoirs should not or cannot be used for drinking water purposes. At the moment this affects mainly the small individual water supplies which abstract water from wells and short drillings.

Based on an overall evaluation of the different aspects of the nitrate load and run-off in the various ground water reservoirs, it can be estimated that around two-thirds of the current ground water formation is so poor in quality that it limits its usefulness for water supply purposes.

Summing up, the pollution of the upper reservoirs and a naturally poor water quality in the lower reservoirs, means that the ground water zone which is well-suited for abstraction of drinking water is currently narrowed. (Figure 3.2 and 3.3).

3.1.3. **Ammonium in the ground water**

Oxidation of ammonium

Ammonium from agricultural areas will, while percolating, very quickly be transformed into nitrate through an oxidation process. Farming does not therefore generally cause ammonium contamination of ground waters. The oxidation of ammonium, however, is a acidifying process which leads to acidification of the newly formed ground water (National Agency of Environmental Protection 1986). Moreover, ammonium occurs naturally in marine deposits, but in relatively low concentrations. In a well-functioning water treatment in the waterworks ammonium will first be oxidized into nitrite and further into nitrate which, in relatively low concentrations, does not generally pose any health hazard.

3.1.4. **Phosphorus in the ground water**

Fixation of phosphorus

As described in Chapter 2.1., there is a loss of phosphorus from agricultural areas, primarily to marine and fresh waters by surface run-off and drainage. Since both sandy and clay soils have a large fixation capacity for phosphorus, agricultural phosphorus in not presently considered as a serious ground water problem. In sandy areas, it is the content of aluminium hydroxides and oxidized iron compounds which fixes phosphorus, whereas in clay soil areas, also the content of calcium oxide is important. (Gosk et al. 1990, Rasmussen & Gosk 1990 and the National Agency of Environmental Protection 1990c).

The increased phosphorus concentrations found in ground water somewhere stem predominantly from marine deposits.

3.2. Watercourses

The Danish watercourses have a total length of 65,000 km. Together they form a close network in the landscape.

Spring-fed brooks and watercourses are nature's system of surface drainage of precipitation falling over land and of ground water draining. Watercourses and their immediate surroundings are habitats for an important part of the Danish natural fauna and flora.

Watercourse quality

The environmental and ecological condition of watercourses are estimated on the basis of biological observations, and on observations of a number of living conditions determined by physical, hydrological and chemical circumstances. This applies to watercourses absolutely unaffected by human activities as well as to regulated water courses affected by waste water and water extraction. Watercourse quality may be described by means of three factors – purity of water, flow of water and the physical variation of the watercourse.

3.2.1. From spring-fed brooks to the sea

The majority of Danish watercourses start their flow towards the sea as small ditches collecting surface water, drainage water and ground water. Upstream reaches often dry out in the summer. Downstream reaches of the watercourse becomes permanently waterbearing as a result of a larger constant (diffuse) input of ground water and eventually waste water too.

Springs, brooks and streams

Some watercourses start their flow more concentrated by an immediately visible outflow of ground water. These upper parts of a watercourse are termed springs and spring-fed brooks. Their main characteristics are a rather uniform water flow and temperature (7-9 °C) around the year. The constant temperature and rate of flow have the effect that fauna and flora are often essentially different from all other watercourses. Gradually, as the input of water increases, the spring-fed brook becomes larger and is then called brooks or streams. The water temperature becomes more varied day and night as well as around the year. The composition of species of fauna and flora also becomes different down through the watercourse. (See figure 3.4.)

Variation in run-off in Danish watercourses

The water flow in Danish watercourses takes place according to patterns depending on local and regional climate and soil conditions. Thus, the variation over the year is much bigger in the eastern part of Denmark than in West Jutland. The reason is that here, in addition to the consequences of larger precipitation, the watercourses receive much more ground water than watercourses in the eastern part of the country. The admission of ground water to the watercourses is normally constant throughout the year, and it is thus an expression of the minimum water flow of a watercourse. The normal seasonal variation of the run-off in three watercourses in Jutland and two watercourses in east Denmark is shown in figure 3.5.

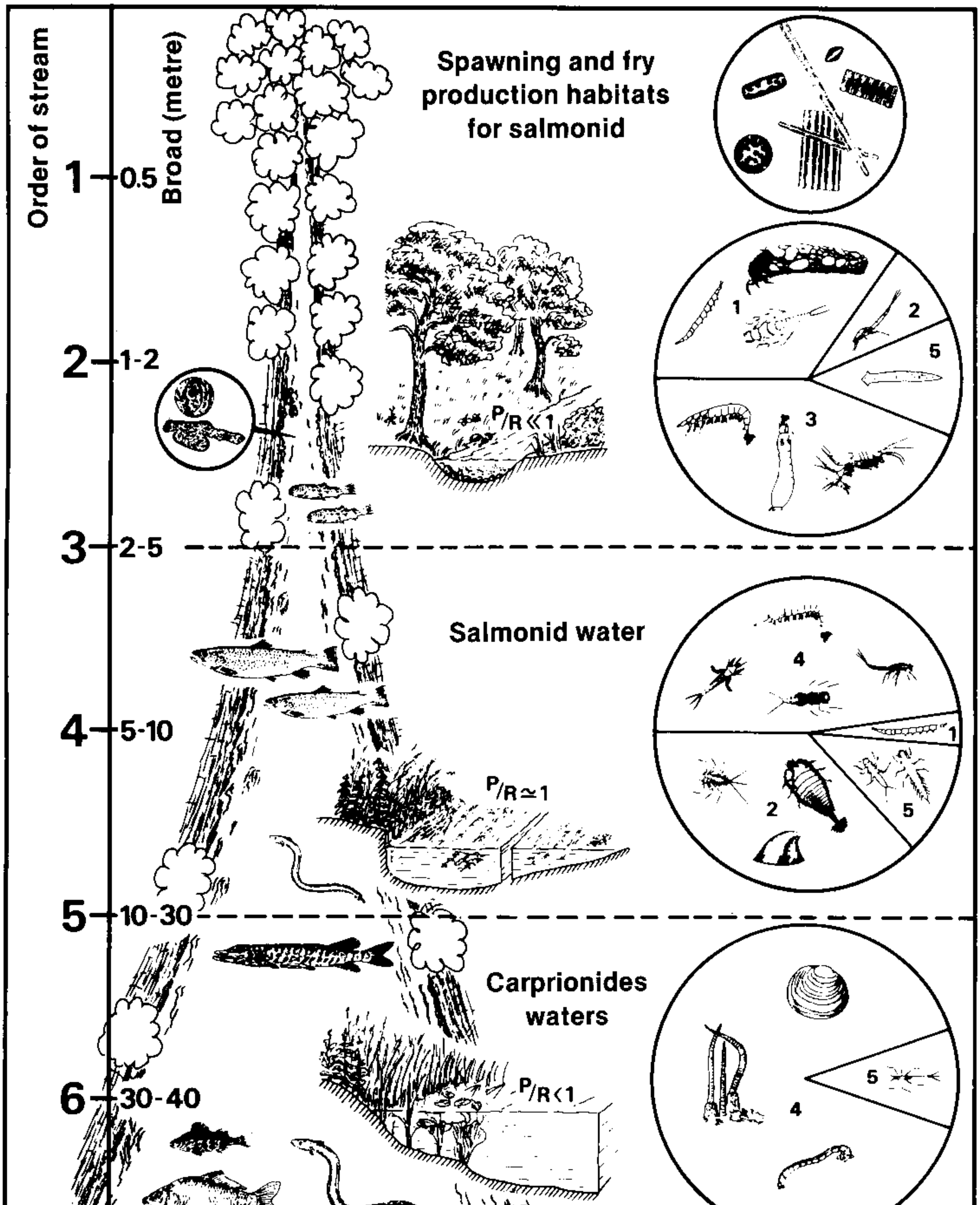

Figure 3.4 **Variations in plant and animal life down through an idealized watercourse system** (the Fresh Water Laboratory of the National Agency of Environmental Protection 1984).

Jutland watercourses

The stream named Gudenå is a representative of the moraine landscape from the last glaciation. The stream Lindenborg stream in Himmerland is marked by the high-lying limestone underground in the catchment area, which gives a high degree of levelling of the runoff over the year. The stream Funder stream runs in a very deep valley just east of the Jutland ridge, and the flow to the stream is ground water which has passed thick aquifers.

East Danish watercourses

The stream Lomose stream in Lolland has a catchment area with clay soils and small variations of height. The stream Græse stream in North Zealand runs in an undulating country with quite a few sandy soils which gives a larger summer run-off than in the stream Lomose stream.

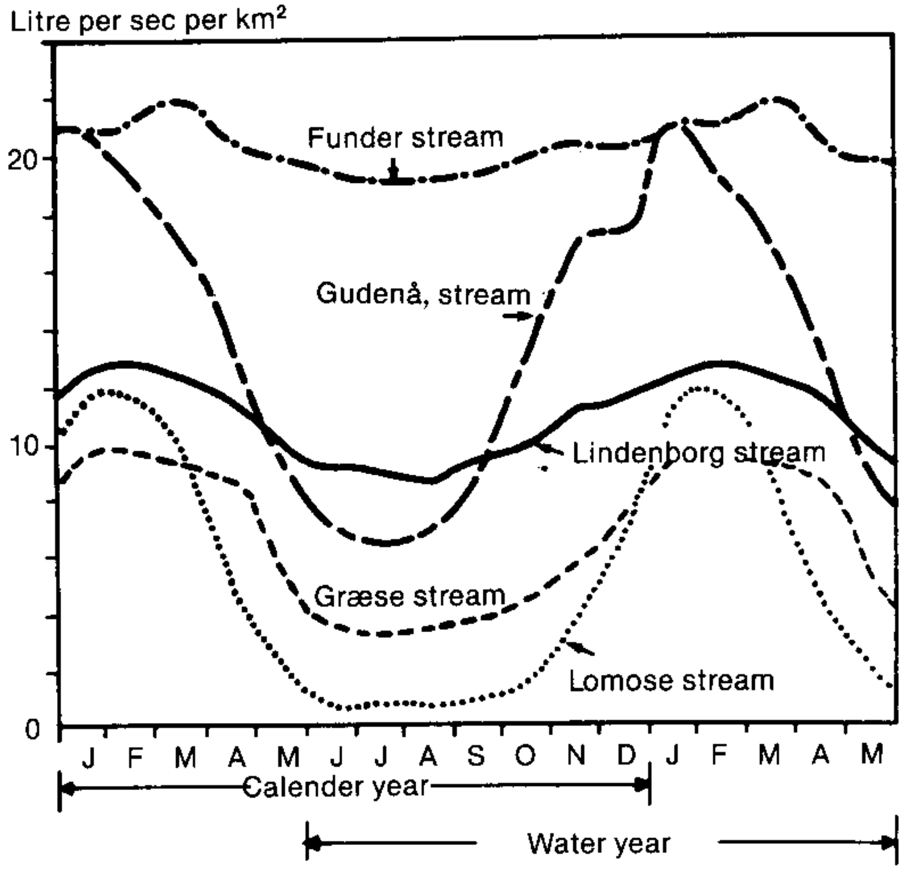

Figure 3.5

Normal seasonal variations in the streams Gudenå, Lindenborg stream, Funder stream, Lomose stream and Græse stream (according to Kern-Hansen et al. 1984).

3.2.2. Watercourse systems, watersheds and catchment areas

Watercourse system

A watercourse system includes a main course, with outlet into the sea, and all tributaries to the main course by way of brooks and streams, brooks and ditches – including any piped reaches and the lakes with discharge through the watercourses of the system.

The catchment area

The catchment area of a watercourse system is the area from which discharges to the watercourses take place. If the term »catchment area« is used without any further definition, it generally means the topographical catchment area, i.e. the area within which all precipitation will find its way to the watercourse, if the surface of the ground was impermeable. The boundary line between two topographical catchment areas is called the watershed.

As distinct from the topographical catchment area, it is in certain cases relevant to speak of the ground water catchment area, i.e. the area from which the ground water flows to the catchment area under review. The ground water catchment area is not always identical with the topographical catchment area.

3.2.3. **Discharge of pollutants to watercourses**

Watercourses receive pollutants by way of organic matter, nutrients, and environmentally hazardous substances, as a result of farming, discharge of waste water from water treatment plants, industry, fish farming, and scattered houses.

Organic matter

Traditionally, input of organic matter has been the largest pollution problem in watercourses. The primary effects of pollution by organic matter is a fall in the oxygen content of water as a consequence of oxygen consumption of microorganisms by the decomposition of organic matter (see figure 3.6).

Pollution by organic matter changes the physical living conditions of fauna and flora in the watercourse, because organic particles are deposited as sludge at the bottom, and because all surfaces may be covered by greasy coatings of fungi and bacteria (sewage fungi). The more a watercourse suffers from loads of organic matter, the more extreme and uniform the conditions become for fish and small animals. The number of species will therefore be reduced, as the individual species will simply die or go elsewhere, if the conditions of their habitat disappear. Instead, under such conditions there will be a large number of individuals of some species which can utilize the added organic matter as feed.

Nitrogen and phosphorus

Input of nutrients (nitrogen and phosphorus) to watercourses has, first of all, an effect on the composition of species and the production of algae living at the bottom – and on the composition of species of other aquatic plants. The fauna is directly affected through changes in living conditions by changes in the composition of species of algae and plants. The algae in watercourses assimilate nutrients from the water, whereas other plants are normally rooted and therefore have a possibility of absorbing nutrients from the bottom of a watercourse, where normally there are sufficient amounts of these.

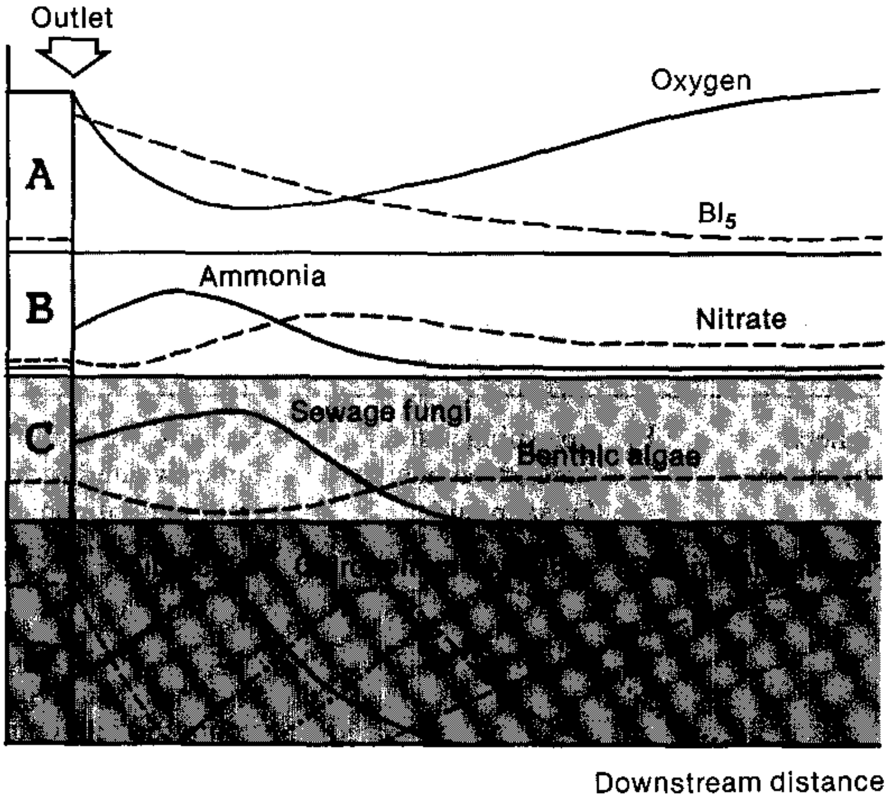

Figure 3.6

Effects of outlets of urban waste water in a small brook with a quick flow in the summer. A: Oxygen and BOD5 concentration's mean and daily variation of oxygen concentration. B: Mean concentration of ammonium and nitrate. C: The biomass of »sewage fungi« and benthic algae. D: The relative number of different groups of small animal fauna (according to Moth-Iversen et al. 1986).

It is normally the phosphorus concentration which is significant and limiting for the growth of algae in watercourses. Nitrogen is often present in such concentrations not to be a limiting factor.

Retention of phosphorus and nitrogen

Through the small summer flow in many watercourses, large quantities of phosphorus are retained in deposits of organic matter and sludge. Nitrogen, however, is not retained in the watercourse. Conversion takes place to a limited extent to free nitrogen by denitrification.

3.2.4. Quality objectives for Danish watercourses

Adoption of quality objectives

The quality objectives for the conditions of the Danish watercourses have been adopted and approved as binding directives in the regional plans of the country councils. A more detailed description of the individual watercourses, and the requirements of the watercourse quality in order to fulfil the adopted objectives, appear in the reports on water quality in the regional and recipient quality plans of the counties.

The quality objectives for watercourses are laid down based based on actual physical and flow conditions, and on the influence to be permitted. The different types of objectives appear from table 3.1.

	Quality objectives		Description	Maximum saprobic index
Strengthened objectives	A	Area with specific scientific interests	Streams with specific natural conditions of interests.	II*
General objectives	B_1	Spawning and fry production habitats for salmonid	Streams which fulfil conditions for spawn and fry production for trout and salmonid (including hatch and fryproduction at fishfarms).	II
	B_2	Salmonid water	Streams which fulfil conditions as growth and living habibats for trouts and salmonid (including trout production at fishfarms).	II
	B_3	Carponides water	Streams which fulfil conditions as growth and living habitats for ell, perch, pike and carponides.	II (II-III)
Eased objectives	C	Streams with runoff interests only		II-III
	D	Streams, affected by waste water		II-III
	E	Streams, affected by groundwater with drawal		II-III
	F	Streams influenced by ochre		–

* Separately established degree of pollution for each stream

Table 3.1 **Types of quality objectives for Danish watercourses** (according to the National Agency of Environmental Protection).

An important part of the Danish watercourses are regulated by general quality objectives (B1, B2, and B3), see figure 3.7 and figure 3.8. A number of watercourses with important natural scientific interests are regulated by a stringent objective (A). In cases where in the utilization of the watercourses makes it impossible to fulfil a general quality objective, less stringent objectives have been selected (C, D, E and F).

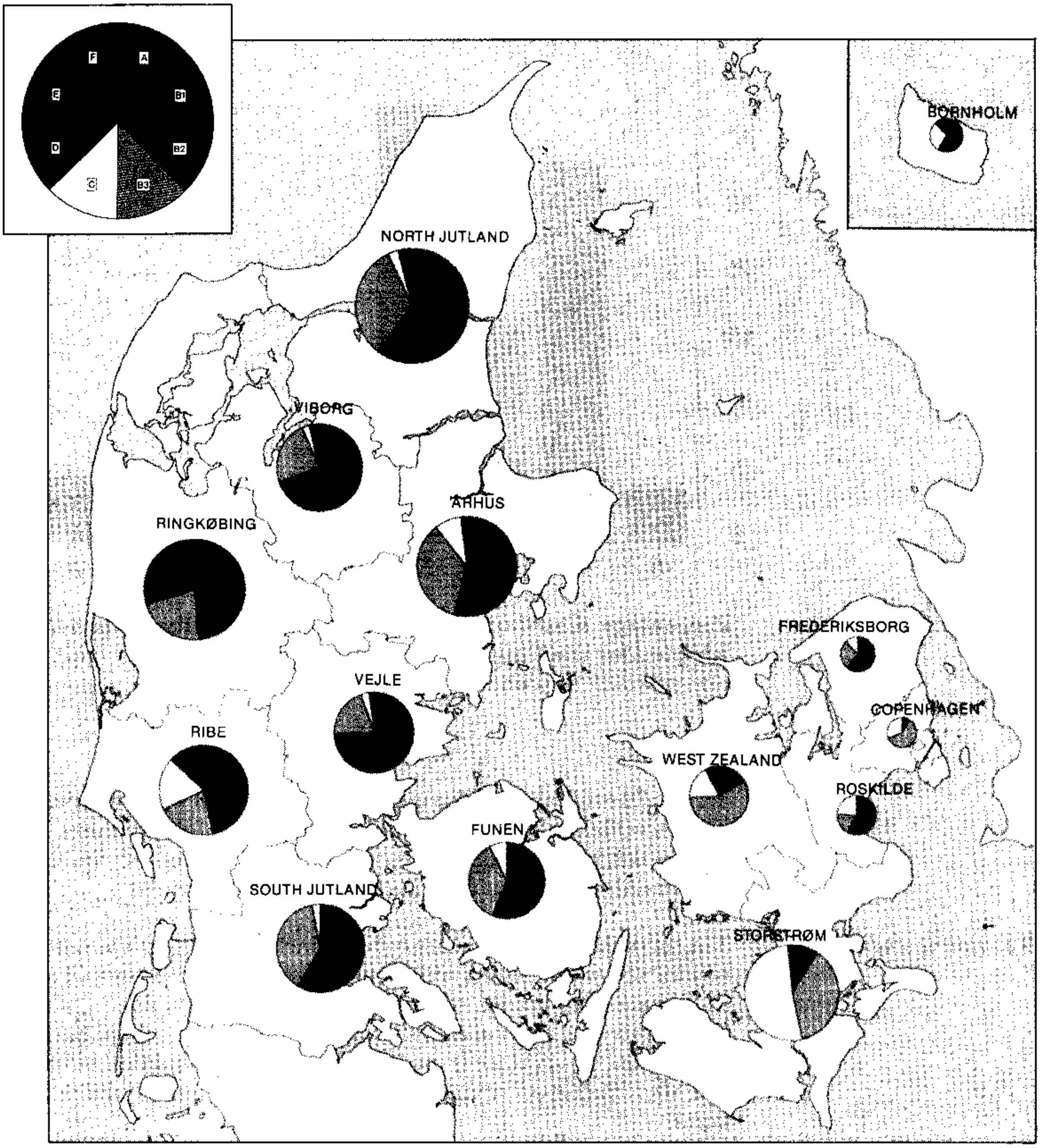

Figure 3.7 **Relative distribution of adopted quality objectives in relation to the length of watercourses having objectives in the Danish counties. The diameter of the circles indicate the length of watercourses with quality objectives in the individual counties related to the total length of the watercourses with quality objectives in Denmark** (according to the regional plan maps of the counties).

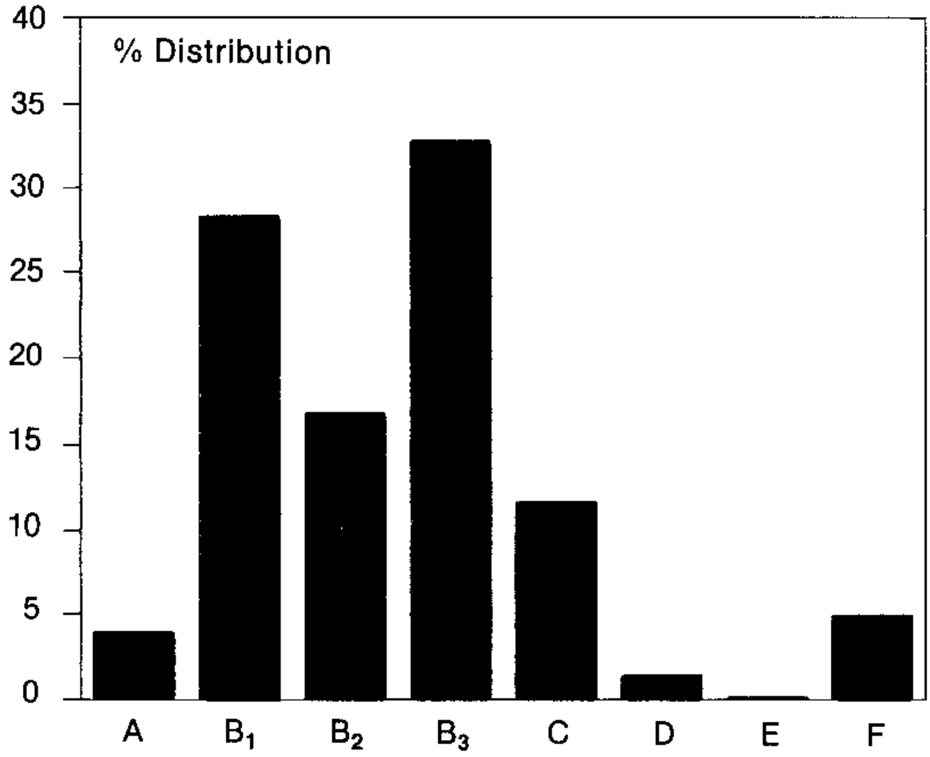

Figure 3.8

Percentage distribution of the types of quality objectives adopted for the Danish watercourses (according to the regional plan maps of the counties).

3.2.5. Surveillance of the conditions in Danish watercourses

The surveillance of the environmental condition of watercourses is carried out by the county councils according to Section 55, cf. Sections 61a and 61e, of the Environmental Protection Act.

Watercourse studies

The surveillance in the county councils include studies of the water flow of the watercourses, water quality and fauna and flora. The studies are often carried out with varying time intervals of entire watercourse systems or of all watercourses in selected municipalities. In addition, surveillance is made of the biological condition before and after discharges from waste water treatment plants and fish farms.

The monitoring programme of the Action Plan for the Aquatic Environment

The monitoring programme of the Action Plan for the Aquatic Environment for spring-fed brooks and watercourses comprises a national and a local monitoring network (National Agency of Environmental Protection 1989). In the national network only watercourse stations with discharge to an inlet or a sea area are included. In the local network spring-fed brooks and watercourses are included. The purpose of the network is to enable documentation on to which extent the reduction objectives of the Action Plan for the Aquatic Environment are fulfilled.

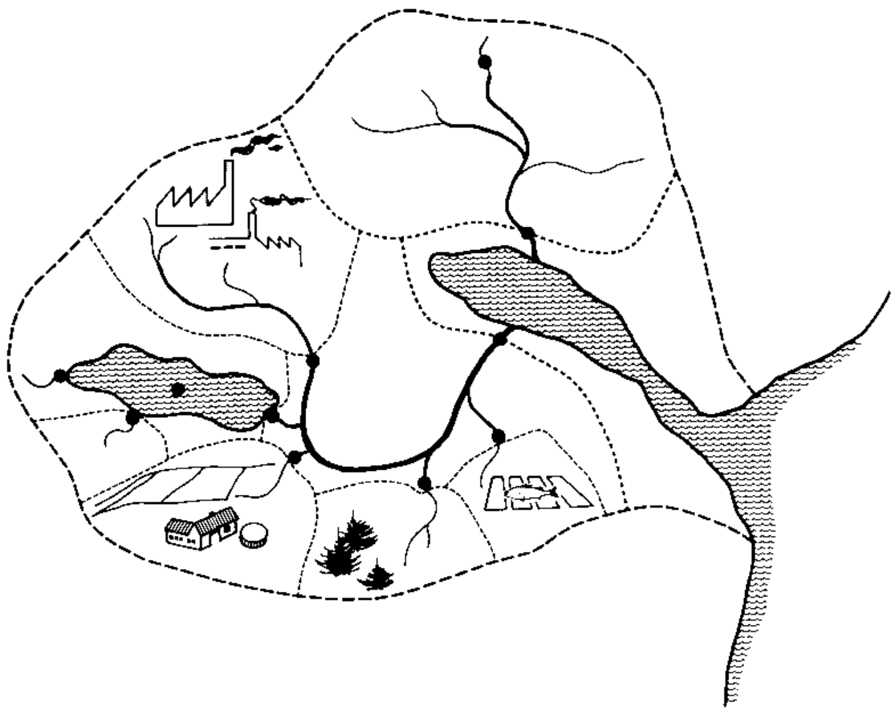

Figure 3.9 **The different types of catchment areas (type catchment areas).**

The localities of the local network have been selected in natural areas on the one hand and on the other hand in catchment areas where the load is mainly coming from a single kind of source (farming, waste water, fish farming), see figure 3.9.

The national network gives a survey of the input of organic matter, nitrogen and phosphorus to the marine waters surrounding Denmark. Similarly, the local network enables analyses of the developments in concentrations and transport of organic matter, nitrogen and phosphorus in water courses, which drain catchment areas with different degree of utilization.

3.3. Lakes

Danish lakes are mutually very different. The reason is that each lake has its own morphological caracteristics, i.e. water flow, water deposit time, soil conditions in catchment areas and loads conditioned by cultural circumstances, etc. Lakes, therefore, must be looked upon individually based on natural and cultural conditions.

The natural lake

After the formation of the lakes, leaching of nutrients from surrounding areas has been an ongoing process. The substances have partly be settled in the sediment, partly been removed again. The leaching is most advanced in the West Jutland moraine landscapes and in the sandy heathland plains. The natural lake development in the lowlands of North West Europe has been a development from nutrient-rich to nutrient-poor lakes. Due to differences in soil conditions in the runoff areas, there is an even transition from lakes naturally poor in nutrients to lakes naturally rich in nutrients.

Lakes affected by culture

In the open, cultivated and inhabited landscape, this development has gradually changed to the opposite throughout the past 100 years as the increasingly intensive exploitations of soils and the sewage and waste water discharges from urban areas have led to a continued increase of nutrients concentrations in most Danish lakes.

3.3.1. The Danish lakes

Danish lakes

Denmark has 468 lakes exceeding 5 ha. In addition, there is a much larger number of lakes and water holes below 5 ha (Danmarks Statistik 1968). The typical Danish lake, exceeding 5 ha, is characteristic in being relatively small, shallow and having a short deposit time of water. The average catchment area is 97 km. The median size is only 11 km (table 3.2). The median expresses the size of the lake in the middle of a list where the lakes are listed according to size.

	Average	Mean	Max	Min
Catchment area (km^2)	97	11	1500	0.16
Area (km^2)	1.1	0.22	42	0.05
Mean depth (m)	2.9	2.0	16.3	0.2
Maximum depth (m)	6.1	3.7	37.4	0.2
Retention time	1.6	0.3	27	<0.01

Table 3.2 **Data on Danish lakes larger than 5 ha** (Kristensen et al. 1990b).

3.3.2. **Nutrient load to Danish lakes**

Retention of nutrients in lakes

The biological community in lakes changes considerably through changes of the input of nutrients – and thereby accordingly changes in the nutrient level of lake water. Part of the nutrients added from the surroundings are sedimented and deposited permanently in the lake bottom or is lost by denitrification. The average loss for phosphorus in many lakes has been found to be about 25% of the load and about 43% of the load for nitrogen (Kristensen et al. 1990a).

Phosphorus and biological conditions of the lake

A close connection has been found between the phosphorus concentration and the biological community in lakes (Kristensen et al. 1990b). In general, nitrogen occurs in lakes in so high concentrations that it is not limiting plant production.

The clean, shallow lake

The clean and shallow lake with a low phosphorus concentration is characteristed by a large occurence of bottom plants. The primary production takes place in this connection and in connection with microscopic algae on the surface of plants and on the lake bottom, whereas the amount of plankton algae is low and often dominated by yellow algae. The lake water is clear. The fish stock is dominated by the predatory fish, pike and perch, whereas the amount of plankton feeding fish such as bream and roach is low (figure 3.10).

Changes in the biological community of the lake

With increasing input of nutrients, more bottom plants, small animals and fish are produced. At the same time, however, a number of qualitative changes and displacements take place between the amount of drifting and rooted algae, bottom plants, zooplankton, bottom animals and fish.

The production in the lake water thereby becomes larger than the decomposition. This triggers off a number of self-reinforcing processes, which make matters even worse.

Bottom plants

Thus, the amount of algae on the surface of the plants is increased, and later the volume of plankton algae in the lake water increases too. Penetration of light for the bottom plants thereby becomes weaker, whereby the depth limit for submarine plants is reduced (Philips et al. 1978, Sand-Jensen 1980). Thus, an exponentially decreasing depth limit is found for bottom plants with increasing phosphorus concentration, so that the bottom plants on an average only reach 1 meter water depth with a phosphorus concentration of 0.15 mg per litre (Kristensen et al. 1990b).

The decline of submarine plants is serious because part of the stability of the ecological system of a lake is reduced thereby (Scheffer 1990). Bottom plants are of great importance to the release of nutrients to lake water as the plants not only stabilize the bottom material, which is thereby not easily whirled up with a resulting phosphorus release, but also take up nutrients from the lake water.

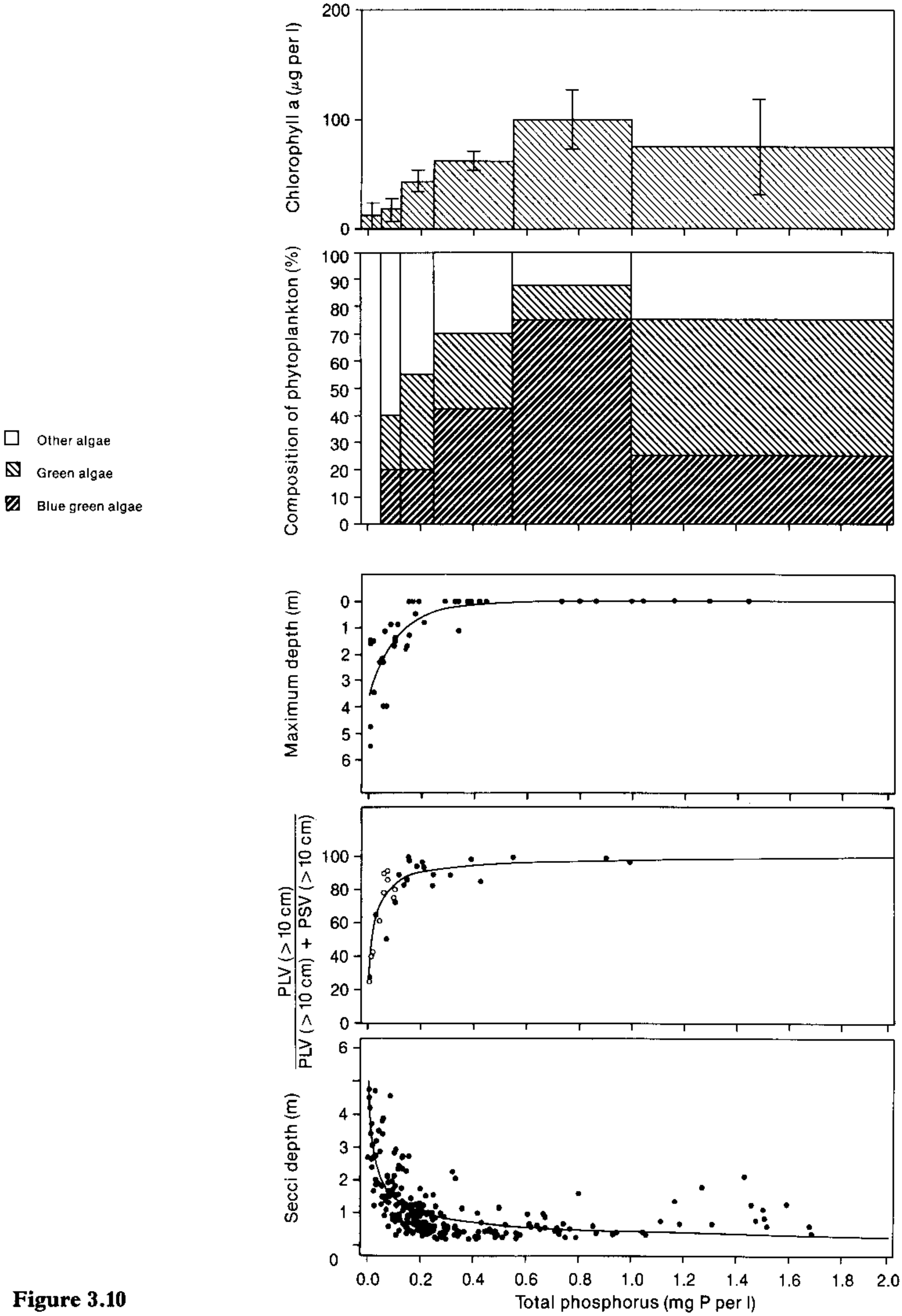
Other algae
Green algae
Blue green algae
Chlorophyll a (μg per l)
200
100
0
Composition of phytoplankton (%)
100
90
80
70
60
50
40
30
20
10
0
Maximum depth (m)
0
1
2
3
4
5
6
PLV (>10 cm) / PLV (>10 cm) + PSV (>10 cm)
100
80
60
40
20
0
Secci depth (m)
6
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Total phosphorus (mg P per l)

Figure 3.10

Figure 3.10

The interrelation between average chlorophyll a concentration, the percentage distribution of dominant plant plankton classes, depth limit of distribution of bottom plants, relationship between plankton feeding fish (PLV) and plankton feeding fish + predatory fish (PLV + PSV), mean secci depth in the summer against average total phosphorus concentration in the summer. (Kristensen et al. 1990a).

The concentration of these substances thus becomes lower in the lake water, and therefore less plankton algae are produced. It has been found that lakes with a wide distribution of submarine vegetation generally has a higher secci depth at a given phosphorus concentration than lakes without or with few submarine plants (figure 3.11).

Fish in the lake

Other self-reinforcing processes are also set off with the increase of phosphorus input. The importance of predatory fish declines. Thus, the possibilities of pike are deteriorated as a result of the unclear water in case of an abundant amount of plankton algae. Besides, the decline in the area of distribution of submarine plants is of great importance. Other things being equal, the distribution of predatory fish, such as pike and perch, will decrease if plants disappear.

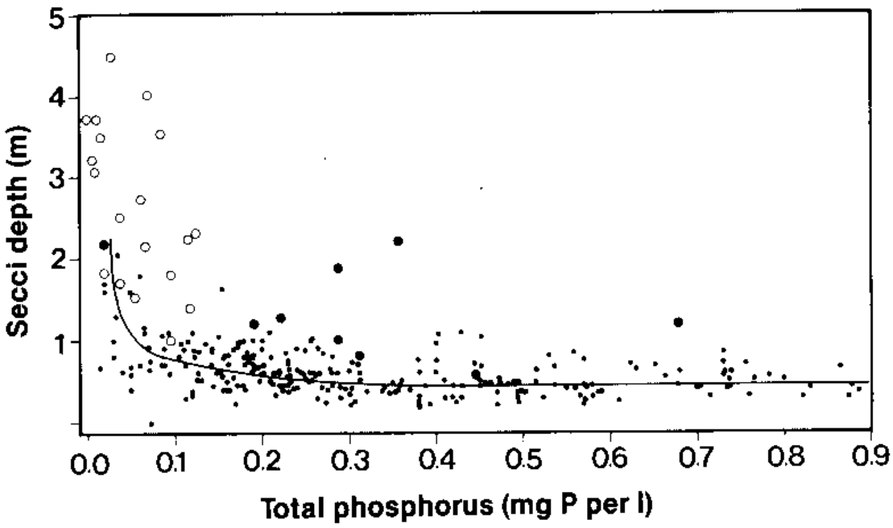

Figure 3.11

The interrelation between mean secci depth and mean total phosphorus concentration (May-September) in shallow lakes (with a mean depth of less than 3 meters). (Jeppesen et al. 1990a).

- ○ **Lakes larger than 3 ha and large occurence of bottom plants,**
- ● **Lakes less than 3 ha and large occurence of bottom plants,**
- • **Lakes without bottom plants or unknown number (Jeppesen et al. 1990a).**

Fish and bottom plants of the lake

Many submarine plants is an advantage for the perch compared to roach and bream. The youngest generations of these fish have the same choice of feed, i.a. animal zooplankton, but the perch is better able to feed among plants than roach and bream (Winfield & Townsend 1988). In open water it is exactly the opposite. Here, roach and bream are superior to the perch. A decline in occurence of submarine plants will favour roach and bream on account of both better competitive conditions for feeding and of a reduced number of predatory fish. In conformity with this, a marked change in the composition of fish stock has been found which, with increasing phosphorus concentration, is changed towards total dominance of roach and bream when the phosphorus concentration becomes higher than approx. 0.08-0.15 mg per litre.

Roach and bream

The increase of roach and bream means that more zooplankton is digested which will then find it more difficult to control the growth of plankton algae. Besides, there will be a shift to partly inedible blue-green algae which will further increase this trend.

If less plankton algae are decomposed in the lake water, sedimentation is increased, and the plankton algae are consequently decomposed in the lake bottom with oxygen consumption and often large release of phosphorus as a result. This in turn will stimulate the growth of plankton algae which will further the already self-reinforcing processes.

The result is unclear water and dominance of blue-green algae and of roach and bream.

Biological collapses

If the input of nutrients becomes extremely large, biological collapses occur, where the lakewater change between clear and unclear conditions, often with a dominance of green algae. This is due in part to considerable year-to-year variations in the volume of fish stock and its age structure caused by periodical piscicides and changing breeding success of the fish. Thereby, a considerable variation in the volume of zooplankton, which is fed on by fish, occurs and thereby also of the volume of plant plankton fed on by zooplankton. Besides, the instability is due to the biological structure becoming one-sided, only consisting of very few species of zoo- and plant plankton and fish (Jeppesen et al. 1990b).

Demands on the phosphorus concentration

The relations in figure 3.10 and figure 3.11 thus indicate that the phosphorus concentration in the eutrofied shallow lakes must be brought below 0.08-0.15 mg per litre, if significant changes are to be obtained in the biological community towards a better balance between predatory fish and their prey, less plankton algae, and especially less blue-green algae, more bottom plants and better secci depth in the water. Below this limit the mentioned self-reinforcing cycles may be turned and thereby instead brought to contribute to improving the state. (Jeppesen et al. 1990a).

The deep lakes

Similar good information does not exist about the biological state of Danish deep lakes as for the shallow lakes. The changes in the biological communities probably take place more gradually than in the shallow lakes, because the importance of submarine plants as a stabilizing factor is not so pronounced. However, it is more difficult to interrupt the dominance of blue-green algae in the deep lakes. Thus Sas (1989) found that a significant reduction in the dominance of these algae did not take place until a level below about 0.02-0.04 mg per litre in a number of deep European lakes, whereas the dominance of blue-green algae is reduced at a level of 0.1-0.2 mg per litre in the low water lakes (Jeppesen et al. 1990a).

Demands on the phosphorus concentration

The level of phosphorus must therefore be considerably lower than 0.08-0.15 mg per litre in the deep lakes in order to obtain a similar improvement in the state as in the low water lakes.

Nitrogen is normally present in sea water in such large concentrations that it has no regulating effect on the eutrophication.

3.3.3. **Objectives for Danish lakes**

The desired state (objectives) for Danish lakes is set up as guidelines in the county regional plans. Since lakes are highly different with regard to ecological background, state and desired use and condition, the system of objectives is developed so that each single lake has its own.

Objectives system

The system of objectives is in principle divided into three parts, with groups of strengthened objectives, basic objectives and a group of eased objectives (table 3.3).

Strengthened objectives

Areas given the strengthened objectives are interest areas of special natural scientific importance, which *i.a.* include lakes which are completely or almost unaffected by human activities and may therefore be used as a scientific basis of comparison in the evaluation of ecological matters in other water areas. Lakes with special plant and animal occurrences, which require special protection, are targeted also as areas of natural scientific interest. Lakes with such objectives must be kept entirely free of influences which may change the ecological state. In the group termed strengthened objectives are included also lakes targeted as water for recreational purposes, such as e.g. bathing, and as reservoirs for drinking water.

	Quality objectives		Description
Strengthened objectives	A_1	Area with specific scientific interests	Lakes with specific scientific interests.
	A_2	Bathing water	Lakes, which waterquality fulfills the requirement for bathing water.
	A_3	Surface- and ground-water for watersupply	Lakes containing water to be utilized for watersupply.
	B	Natural and diverse for plant and animal life	Lakes with no impact of waste water or other human activities, which affects or only slightly affects the natural and diverse plant and animal life, compared to the basic objectives.
Eased objectives	C_1	Lakes influenced by waste water, with drawal or other physical activities.	Lakes affected by lawful discharges and other activities.
	C_2	Lakes charge by cultivation	Lakes where the basic objectives can not be reached due to the leaching of nutrients from agriculture.

Table 3.3 **Recipient quality objectives for Danish lakes** (National Agency of Environmental Protection 1983).

Basic objectives

The basic objectives are applied to lakes in which it is desired to preserve a natural flora and fauna. Therefore, these lakes may only be influenced by cultural-technical conditions in the runoff area to an extent which does not or only modestly so, influence the ecological state.

Eased objectives

Eased objectives are applied to lakes where the ecological state is so affected by lawful discharges that costs incurred in carrying out protective measures are out of proportion to the possibility of achieving a basic objective.

The physical-chemical and biological requirements for achievement of the objectives for the individual lakes appear from the regional and recipient quality plans of the counties.

3.3.4. **Monitoring of the state in Danish lakes**

Lake studies

Supervision of the state of Danish lakes is entrusted with the counties. The general supervision normally comprises surveys of all targeted lakes between every second and fifth year. An annual supervision is made during the summer period for a great number of lakes with a view to measuring i.a. secci depth, algae concentration and oxygen content.

The monitoring programme of the Action Plan for the Aquatic Environment

In connection with the monitoring programme of the Action Plan for the Aquatic Environment, 37 lakes have been selected in which physical-chemical and biological studies are carried out each year.

3.4. **Marine water areas**

The environmental state and the ecological conditions in Danish marine waters are evaluated on the basis of biological observations related to a number of living conditions. Living conditions are by nature determined fundamentally by climatic, physical and chemical conditions, but they are also affected by human activities. In connection with the Action Plan for the Aquatic Environment, interest is especially focused on the input of nutrients, their transportation and decomposition and not least the ecological effects thereof.

3.4.1. **Physical and hydrographical conditions**

Danish marine waters comprise three main areas with the inner waters being a transition area between the brackish water in the Baltic Sea and the salty water in the Skagerrak and the North Sea. The marine waters are divided into nine water areas, for which the input of nutrients from land are calculated.

Main area	Surface area km^2	Volumen km
The open sea	575.000	40.000
The North Sea		
Skagerrak		
Internal Waters	40.000	800
Kattegat		
The North Belt		
The Little Belt		
The Great Belt		
The Sound		
The South Belt		
The Baltic Sea	372.000	21.000

Table 3.4 **Danish main water areas.**

The internal waters are relatively low-watered sea areas with water depths below 30 meters. Only in the eastern part of the Kattegat along the Swedish west coast is a fairway with depths of 30-50 meters in the southern part and down to 100 meters in the northern part of the Kattegat. This fairway is the southern offspring of the deep Norwegian fairway which extends along the south Norwegian coast with depths in the Skagerrak of more than 700 m.

The Baltic Sea is delimited from the internal waters in a special way. At the Sound (near Drogden) and in the eastern part of Femern Belt south of Gedser are two low-water barriers which are of decisive importance to the water exchange between the Baltic Sea and the Belt Sea/Kattegat.

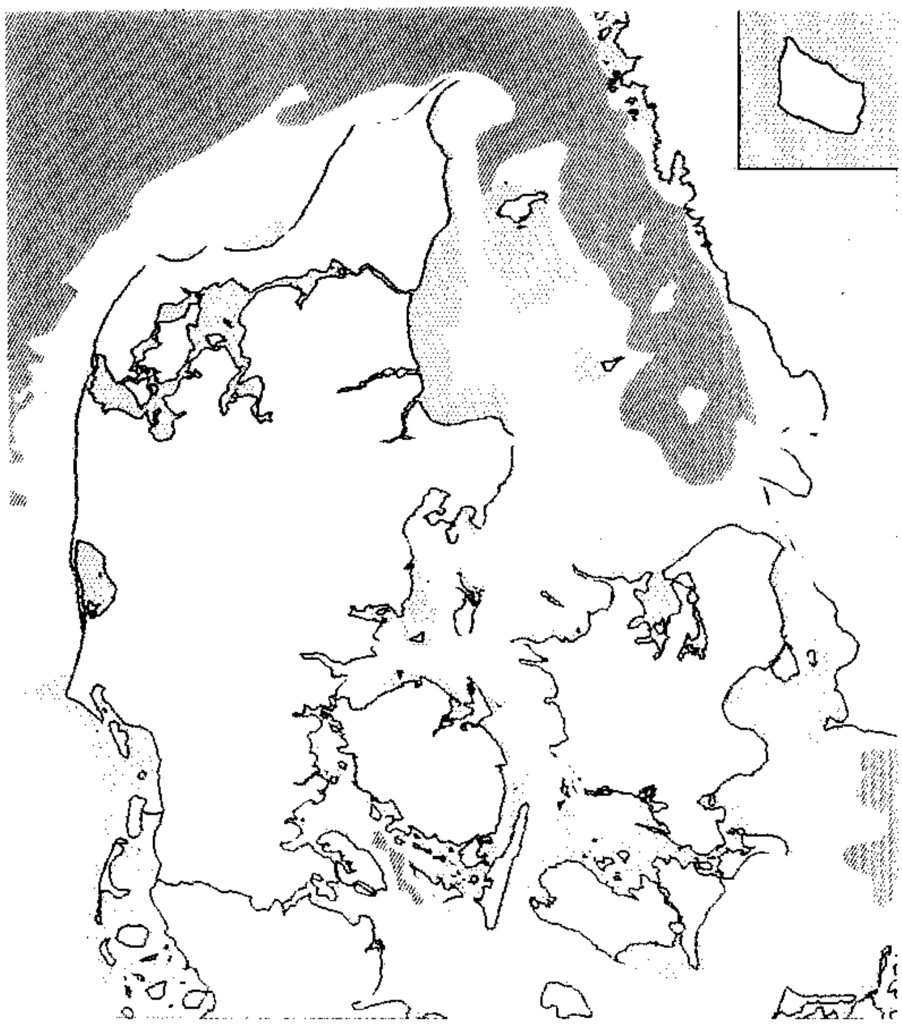

Figure 3.12 **Map of depths in the internal Danish marine waters - 10 m, 20 m and 30 m depth limits** (According to Politiken 1968).

Currents

The conditions of the individual waters are very dependent on currents and water exchange with adjacent areas and not least the open sea areas. The open sea areas have some general current patterns.

Figure 3.13 shows the main current pattern of Danish marine waters. The current pattern changes depending on wind conditions over the entire North and Baltic Sea area and, especially in the Kattegat/Belt Sea, the surface currents alternates between outgoing and ingoing directions. Conditions in coastal waters vary from open coastal areas with good water exchange to more or less closed inlet areas where local conditions can be of vital importance for the water exchange.

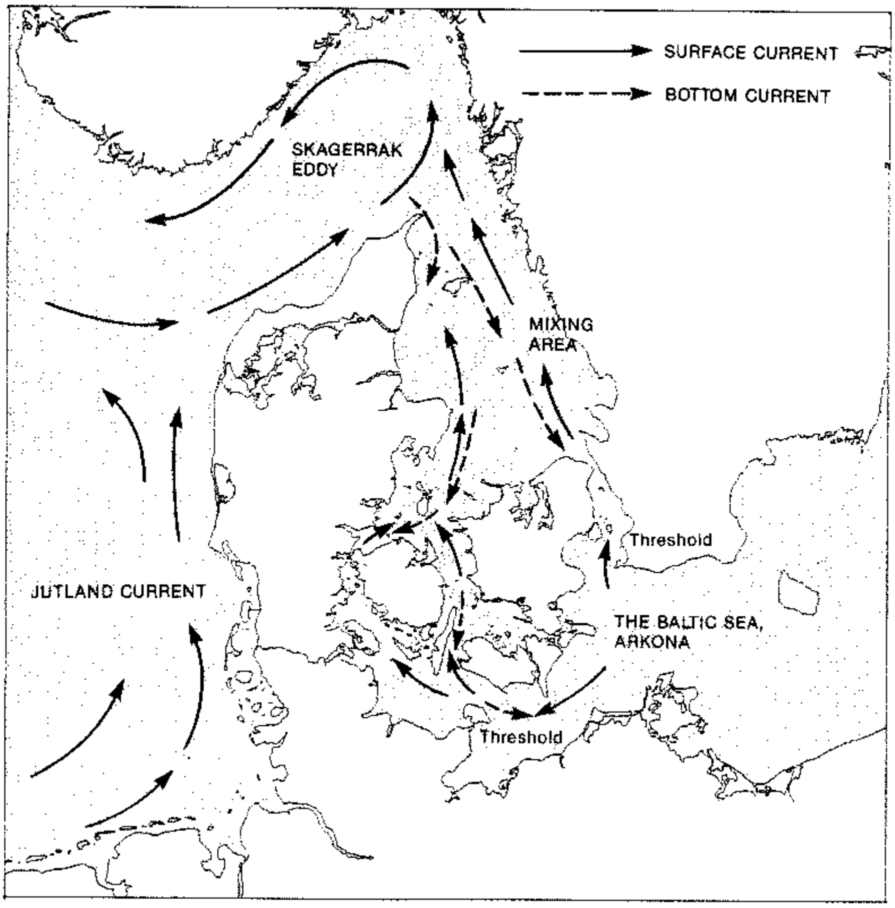

Figure 3.13 **Chart of the main current patterns in Danish marine waters.**

As transitional area between the Baltic Sea and the North Sea, the internal Danish waters are characterized by two main current patterns. There is a northerly surface current of water with low salinity (7-8‰) flowing from the Baltic Sea into the Belt Sea and north through the Kattegat. At the same time, there is a southerly current of bottom water with relatively high salinity (approx. 30 ‰) from the Skagerrak south through the Kattegat and the Belt Sea and at times further into the Baltic Sea. As a consequence of the differences in salt content the two water bodies are separated from each other. Through the small low-water passages in the Belts and the Sound, and in the Kattegat too, there is a gradual mixing of the two water bodies. At the same time a levelling of the differences of salinity takes place. The thickness of the brackish surface water becomes less and the separating surface between the two water bodies therefore moves from a deeper to a higher position, from the Belt Sea to the northern Kattegat (figure 3.14). The mixing of the water bodies depends on prevailing winds, but is increased by the heavy flows in the narrow passages in the Belts and the Sound. The efflux from the Baltic Sea is in the range of 950 km^3 a year, but of this about half has flowed to the Baltic from the Belt Sea giving a net outflow of approx. 500 km^3 a year.

Along the west coast of Jutland is a northerly coast current, known as the »Jutland current« with a salinity just under the salinity of the North Sea water. The lower salinity is due to the large additions of fresh water from the German streams, the Elbe, the Weser and the Ems, flowing into the German Bay. The salinity in the »Jutland current« increases towards the north as mixing takes place with North Sea water.

The Skagerrak is an area of mixing, receiving water from the west with origin from three marine areas. Atlantic bottom water with high salinity (over 35 ‰), North Sea water with mean salinity of 33-35 ‰, and in periods the »Jylland current« with salinities of less than 33 ‰. From the south the Skagerrak receives water from the Kattegat with relatively low salinity (28-30 ‰). In the Skagerrak proper, the main current is made up of what is called the »Skagerrak-whirl« flowing against the clock, i.e. the water coming in from the west and south runs towards the east to the Swedish coast, north along it, and then towards the west and north along the Norwegian coast (figure 3.13). It is also from this water body that there is an inflow into the Kattegat, with a contribution from the »Jutland current«.

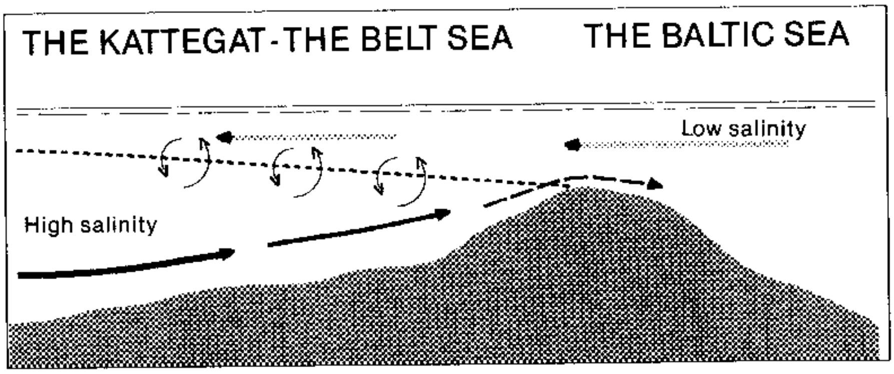

Figure 3.14 **Principle of stratification and salinity in the inner waters.**

The main current patterns and mixing conditions in Danish waters are under strong influence by the meterological conditions. Especially, changing wind directions and wind forces may cause considerable variations in the described current pattern. The current in the Kattegat, the Belts and the Sound may thus at short intervals vary between situations with water flowing out of the Baltic Sea (eastern winds) and situations of influx with water flowing into the Baltic Sea (western winds) (Pedersen 1990). During the year the stratification is also different in strength. During the summer it is mostly stable and only very strong and continued winds may break it. During the winter, however, a mixing of the water masses normally and more often takes place.

3.4.2. Input and transportation of nutrients

The input of nutrients into Danish waters takes place by runoff and discharge from land, with precipitation and atmospheric deposition and by water transportation between the different water areas.

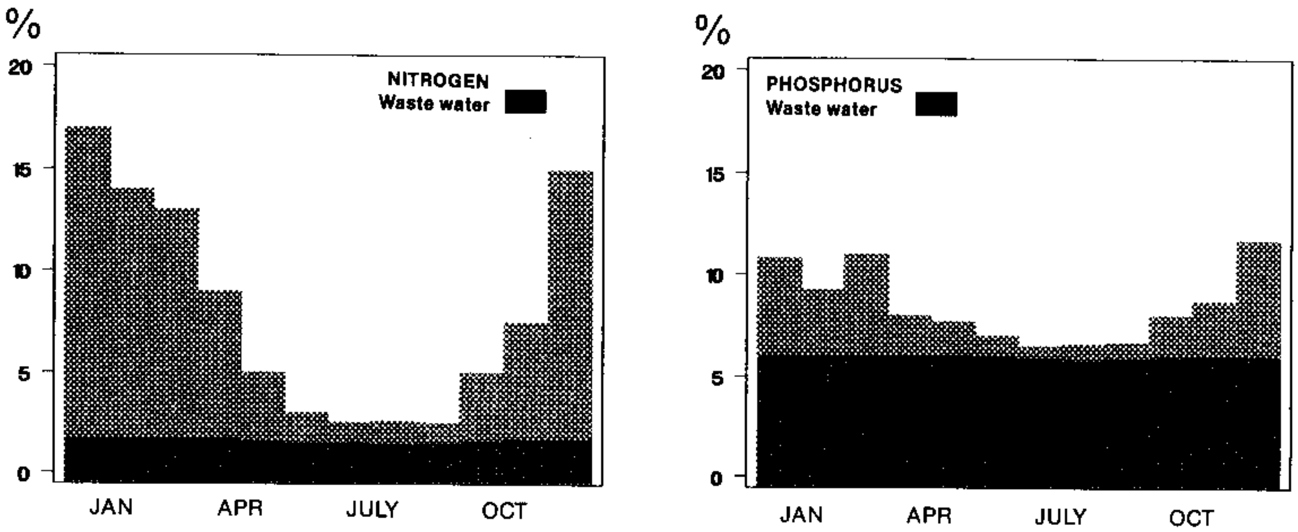

Figure 3.15 **Runoff of nutrients from land.**

Annual variation in input of nutrients from land

The runoff of nitrogen and phosphorus to the sea areas varies during the year. The greatest variation concerns nitrogen where the main part takes place during the winter period in connection with the extensive water runoff. The runoff of phosphorus, however, is more evenly distributed over the year. The input of nitrogen and phosphorus from point sources is rather evenly distributed over the year. Especially where nitrogen is concerned, this means that the discharge from point sources during the summer period constitutes a larger share of the total discharge than on a whole-year basis. This is important for quite a few coastal waters, as input from point sources may constitute the largest nitrogen source during the summer, although on an annual basis it is only constitutes a smaller percentage.

Input of nutrients to internal waters from other sea areas

The water effluence from the Baltic Sea in the south and the water exchange with the Skagerrak/North Sea in the north, each year adds large volumes of nutrients to the internal Danish waters. By far the largest part of this has, however, always occurred and has, together with the original input of nutrients from land and with precipitation, been a contributory factor to establishing the very ecological system which existed before the present environmental effects showed.

It is a fact that the Baltic Sea is influenced by large amounts of nutrients which run off and are discharged from the Baltic countries. Discharges from Denmark are in this connection imperceptible, but indirectly nutrients flow from the Belt Sea into the Baltic Sea with the saline bottom water.

However, only a smaller part of the added nutrients in the Baltic flow to the Belt Sea and Kattegat. The reason is that the mean deposit time of the water in the Baltic Sea is very long (20-30 years), and therefore the main part of the added nutrients are decomposed or withheld in the sediments.

The climatic and hydrographical conditions means that in some years – during the spring where the nutrient concentration is high – there is an inflow from the »Jutland current«. In this way a considerable extra amount of nutrients may be led to the internal waters, first to the bottom water.

3.4.3. **Biology and decomposition of marine areas**

The biological conditions of the marine areas are all-decisive for the decomposition of nutrients although the main transportation of these areas is hydrographically conditioned. The nutrients are consumed by and built into algae and plants in the photosynthesis production. These are part of the food chains of the sea, is built in and decomposed in different forms of living and eventually sinks to the bottom of the sea where, by decomposition, they are released or fixed for ever. The balance of this system is very dynamic, but over a longer period of time some definite patterns show. If then essential and repeated changes of these patterns take place, such as oxygen depletion and lobster and fish mortality, this is the way in which the biological conditions signals that something is wrong.

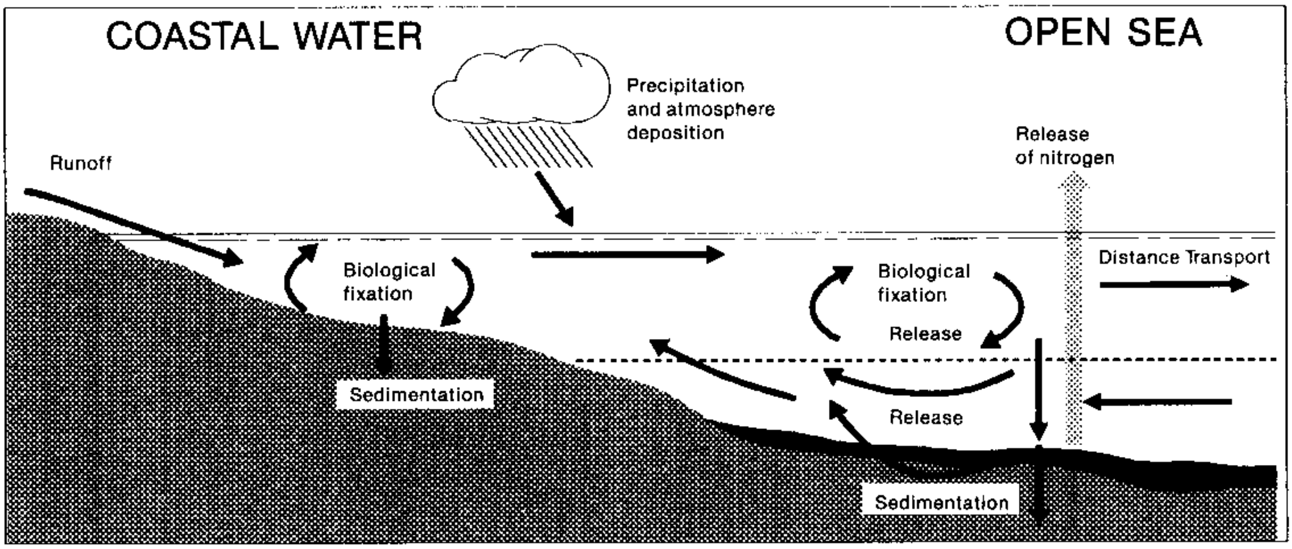

Figure 3.16 **Principle of the stream of nutrients in the sea.**

In the upper parts of the water layers (the photic zone) drifting plankton algae are found which, together with rooted algae and plants at the sea bottom along the coasts, produce by far the most of the organic matter which the marine organisms feed on. The amount of substances produced is mainly depending on the sunlight and the amount of nutritive matter, i.a. nitrogen and phosphorus, which is accessible (i.e. inorganic forms as nitrate and phosphorus) in the water to plankton algae and rooted bottom plants.

The growth and absorption of nutrients in algae and plants are largest in the summertime. It follows a natural yearly rhythm with a heavy spring reproduction of plankton algae, normally fading out when the available nutrients have been used. Then various algae will grow moderately during the spring and summertime and in the autumn a somewhat larger growth may occur before winter.

In the surface water the concentration of available nutrients falls by the algae absorbtion during the spring growth. The concentration of nitrate falls quickly and remains low throughout the summer, but the concentration of the total volume of nitrogen remains at a higher level, which in the open sea areas does not vary much during the course of the year. Nitrogen has become fixed in the organic matter and a new production of algae only takes place to the extent that this matter is decomposed and released or if new available nutrients are added. In a reproduction with the liberated nutrients an effective retention of nutrients is taking place, especially in the free water bodies, until a sinking takes place from the productive zone in the upper water layers.

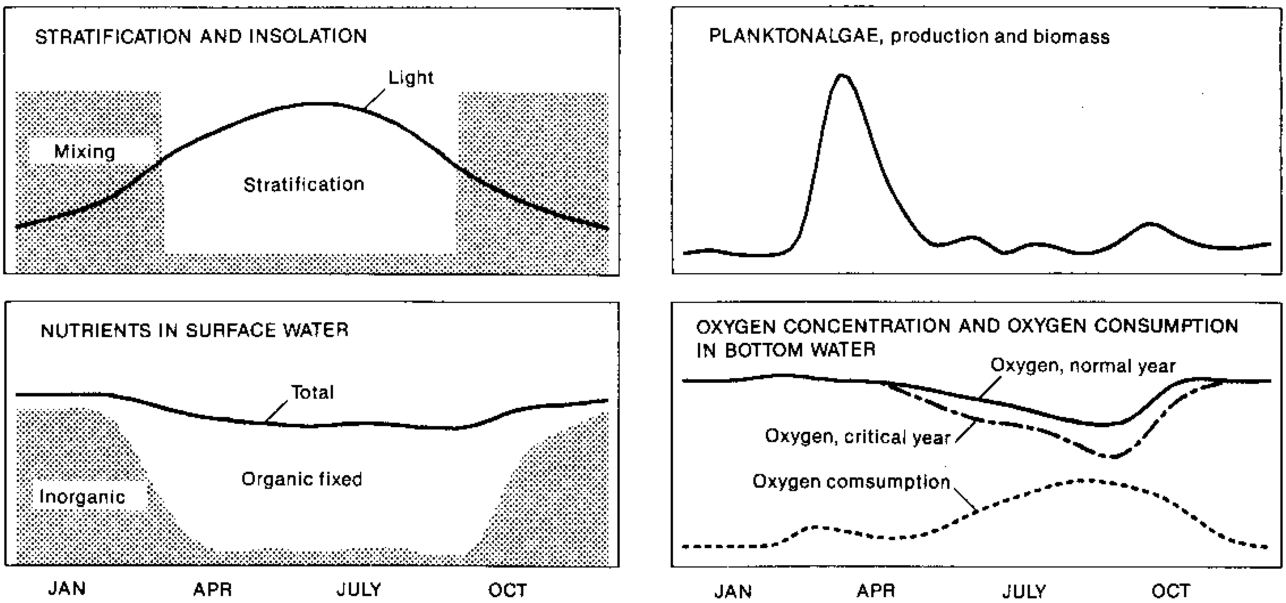

Figure 3.17 **Annual dynamics in nutrients, algae production and oxygen content of bottom water.**

The same pattern applies to phosphorus. The phosphate concentration falls during the spring growth too, but is only found in very low concentrations for a short period. During most of the summer phosphate is present in available form. Nitrogen therefore constitutes the limiting factor for the production and biomass of plant plankton from late in the spring and during the summer. Nitrogen has unambiguously shown to be the most important controlling factor for the photosynthesis production in the period poor in nutrients, both in the open sea areas and in the inlet areas (Kaas et al. 1990). The impact of phosphorus seems limited to specific areas or to short periods of time.

Summing up, the nutrient dynamics mean that it is the amount of nitrate being present before the spring growth (expressed by the winter concentration), and the amount which is mixed from the bottom water during the summer, that are of decisive importance to the condition of the open sea areas. In inlet areas and coastal waters, the input and local regeneration of nitrogen during the summer period is of decisive importance too (Kaas et al. 1990).

3.4.4. The open sea areas

Generally, open sea areas have such water depths that the larger rooted algae and plants do not have adequate living conditions. In the free water bodies, organic matter is produced in drifting plankton algae as food for zooplankton and further for fish, among others. From all organisms in the free water bodies, organic matter sink to the bottom of the sea where it is decomposed or serves as feed for bottom organisms. A larger part of the photosynthesis production of the algae, especially from the spring growth, is part of this. The nutrient concentration of bottom water is thus generally higher than that of surface water. By mixing of the water masses during the summer, but especially in the autumn and winter, the nutrients of the bottom water return to the surface water.

Animal life of the bottom

Traditionally, Danish waters have been divided according to dominating bottom animals in different areas. The differences reflects the requirements to bottom conditions , salinity, etc. of the different bottom animals. The larger part of the marine fauna live as bottom animals. Some of them has a free-living larval stage, but only relatively few species spend their entire life in the free water masses. Bottom animals are mainly stationary, and the amount and composition of organisms in an area reflect the sum of influences which the area has been exposed to for a longer period.

In an unaffected or slightly affected area, oxygen conditions in general will be good and a relatively thick oxidized sediment layer exists. Here some animals will live on the bottom, but in the bottom itself is also found a complex animal community with many different species. The animals live more or less stationary in canals and passages or dig their way through the sediment. Larger animals such as langoustine live in passages dug deep into the sediment. The major part of bottom animals serve as feed for of fish.

The bottom animals are in different degrees prepared for critical situations with low oxygen concentrations. In such situations fish may flee to more oxygen-rich areas. A large part of animal life has evolved in different ways enabling them to handle the situation, either physiologically or by a great ability of regeneration.

3.4.5. **Coastal waters**

Coastal waters, and especially closed coastal waters, offer very changing and often extreme living conditions for plant and animal life. Salinity is often lower than in the open sea areas and may vary considerably during the year. The more or less closed and protected nature in coastal waters cause these areas to collect an organic and inorganic nutritious basis from land or from saline ocean water. The biological conditions contribute to a high degree, and are by nature composed for higher decomposition than the open sea areas. This applies to both drifting and rooted algae, to the entire bottom vegetation and the associated animal and fish life. The rooted vegetation along the coasts forms communities depending on the nature, depth and bottom conditions of the coast. In soft, sandy and quiet bottom areas, the eelgrass community is found down to a depth of 10-15 m. In more rocky coasts the predominant vegetation is perennial rooted larger algae, often with a wider range in depth than eelgrass. All these vegetation areas shelter a rich animal life and is an important reproduction and hiding place of many fish.

Nutrients and algae production in coastal waters

The bottom vegetation of perennial algae and plants is a central element in the way coastal waters hold on to the nutrients in order to have a basis for production in periods with low input of nutrients and low concentrations of available nutrients. Thus, the coastal waters to a certain degree function as a filter for input of nutrients to the open sea areas.

The concentration of the nutrients nitrogen and phosphorus have the same characteristic annual course as in the open waters. It may, however, have another form and far higher levels, depending on the input of nutrients from land and the water exchange with the open waters.

As examples of this, it has in figure 3.18 been chosen to show conditions in the open part of the Great Belt, and in the inlets Horsens Fjord and Roskilde Fjord.

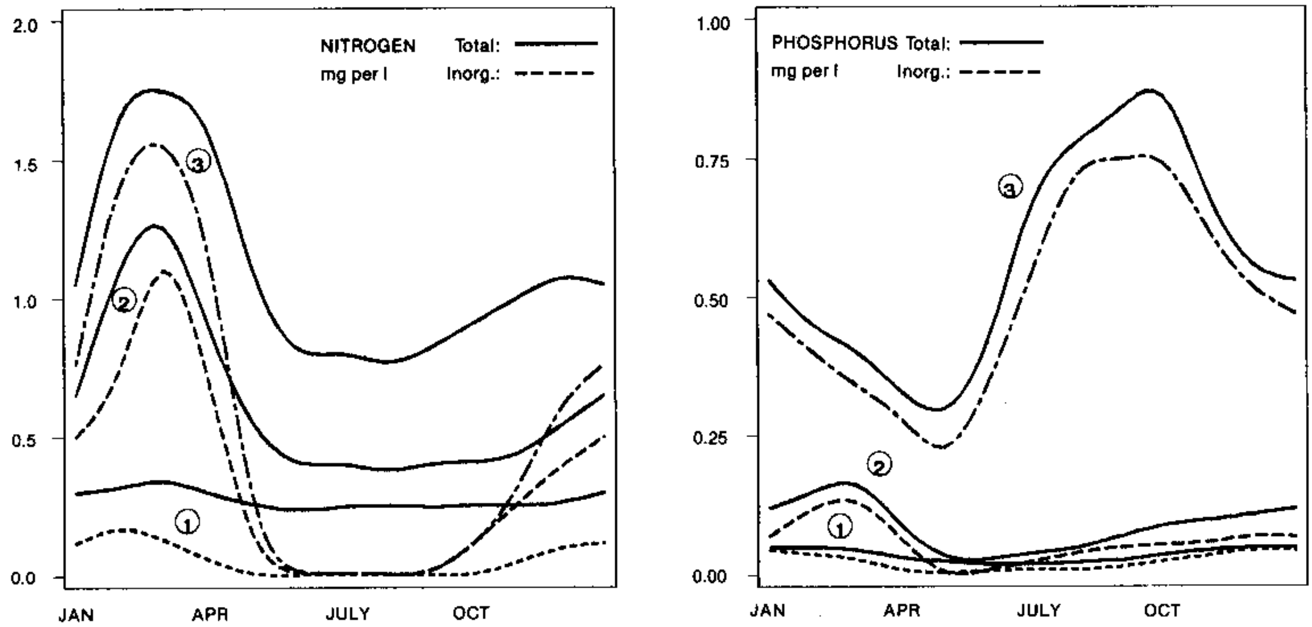

Figure 3.18 **Dynamics of nutrients in coastal waters.**

The concentrations of both nitrogen and phosphorus are highest in the environmentally most affected areas, usually with clear increases in through the inlets both in winter and in summer time. In the course of the year, the highest concentrations occur in the winter period, where the biological activity is small and where runoff from land is high. No matter how high the winter concentration has been, nearly all areas show during the summer months low concentrations of nitrate available for the growth of plants. This means that the growth of plants during this period takes place solely as a result of the amount of nitrogen added either from land and with precipitation or from decomposition of nitrogen fixed organically.

The total nitrogen concentration, which is an expression of nitrogen fixed organically and inorganically, is not, as in the open sea waters, on a relatively constant level round the year, but varies much more and with much higher winter values. During the summer period the level is, however, more or less the same from one year to the next, irrespective of different winter concentrations, but seems mostly to be dependent on the amount of nitrogen added during the summer period. The waste water load during the summer period constitutes in fact a larger share of the nitrogen input than during the rest of the year. In the example shown in figure 3.18, more than 90% in the inlet Roskilde Fjord and approx. 60% in Horsens Fjord.

The growth-limiting role of phosphorus is often brief during the spring and declines during the growth period, as a quick release takes place of the organically fixed phosphate. Besides, in many inlets a stronger increase is seen in the phosphate concentration than should be expected as a result of the input and release in connection with decomposition of the year's production, e.g. for Roskilde Fjord. This is explained by an accumulated mass of phosphorus in the bottom sediment, generally from waste water discharges.

3.4.6. **Effects of increased nutrient load**

If the input of nutrients to a water area is increased, the result is first of all an increase in the amount of organic matter produced by algae and plants.

Eutrophication

The process is called *eutrophication*. Up to a certain limit, the increased production can be decomposed without any essential changes in the biological conditions, but if the increase continues of nutrients available for algae, the system will no longer be able to decompose the increased production in the same balanced way as before. The system is disturbed and the natural dynamics are changed. During the entire period, biological conditions change, some living forms decrease, some increase. In general, the changes are from complex forms of life to more primitive forms of life. Usually, the decomposers (bacteria and fungi) of organic matter - and thereby the consumption of oxygen - will get greater importance in the balance of the system.

More frequent mass growth of plankton algae or growth of special types of algae has in a number of situations shown to have direct harmful effects, such as fish mortality, bottom fauna mortality, discolouring of water, production of foam and smell problems. In growth of poisonous (toxic) algae, problems may arise for fishing especially for shellfish, marine aquacultures may be hit and tourism and recreational interests become affected.

Bottom animals and eutrophication

Decomposition of organic matter takes place by consumption of oxygen. Therefore, it is important for the balance of the system that an equilibrium exists between production of organic matter, input of oxygen and the subsequent oxygen consumption in connection with decomposition.

In open marine areas and in deeper local areas in the coastal waters, the eutrophication results in increasing amounts of organic matter sinking to the bottom of the sea. This provides a larger amount of feed for bottom animals, but it is at the same time decomposed under a larger consumption of oxygen than before. If at the same time there is a stable stratification of the water masses, with a small input of oxygen from the surface to the bottom, a depletion of oxygen may develop.

With the increased amount of feed a change in the composition of bottom animal species takes place. By smaller increases, the number of species, number of individuals and the biomass will increase. In the event of a further load, the number of species and normally also the number of individuals will start to decrease again, as a lower availability of oxygen will then begin to be important. The reaction of bottom animals will then depend on how low the oxygen concentrations become, their frequency and duration. The natural survival mechanisms of the animals become insufficient and a general displacement will take place of the present species towards the more robust forms.

On account of the increased oxygen consumption of the sediment, the borderline to the layers of the sediment without oxygen will gradually shift up towards the sediment surface. The large species digging deep therefore disappear first. In case of strong loads, the sediment may gradually be totally depleted of oxygen. Under such circumstances, toxic hydrogen sulphide, the so-called »paper white crust« may occur, and only few species will survive. The bottom animals have a great ability to regenerate after a few such occurrences

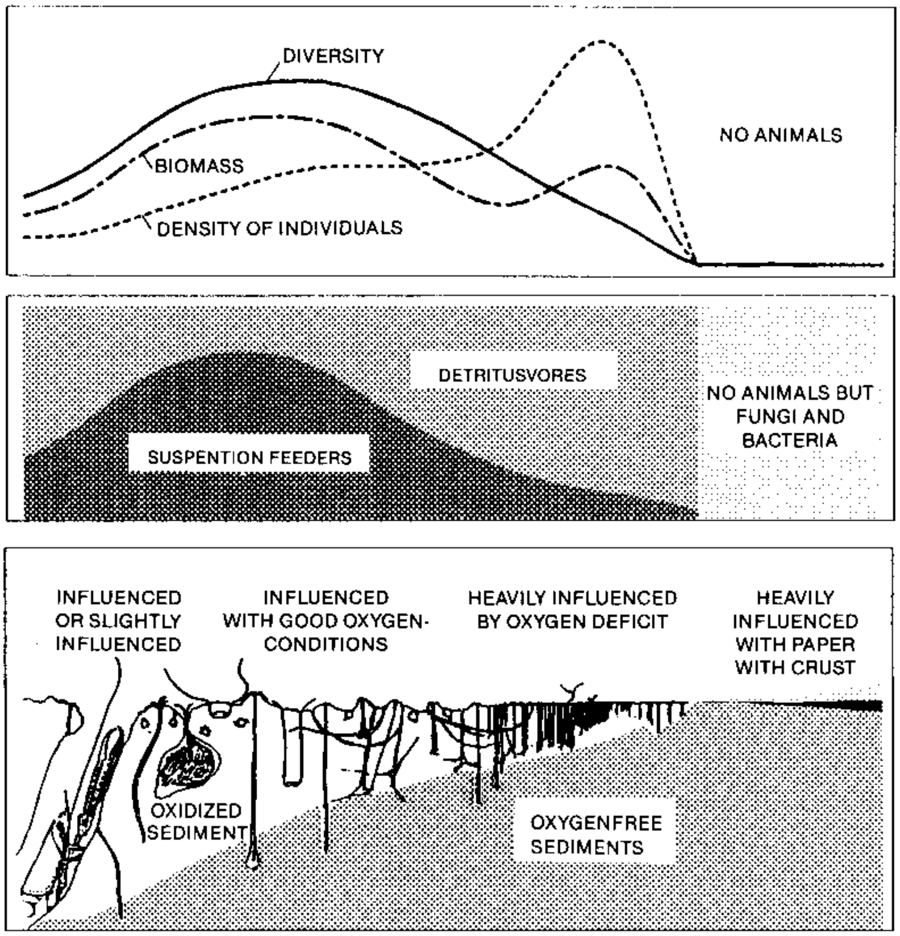

Figure 3.19 **Changes in the animal life at the sea bottom with increasing influence from organic matter** (according to Pearson et al. 1978).

space over a period of many years. If the frequency and the duration of the occurrences increase the changes will, however, become of a more permanent nature and permanent damage will be result.

Fish are often affected later than bottom animals as they are able to escape to better conditions. Gradually, as the presence and composition of bottom animals change, the feed basis is, however, deteriorated and the living conditions of fish disappear. With widespread oxygen depletion and development of hydrogen sulphide, the fish may, however, be »caught« and occurrences of fish mortality occur.

Eutrophication and vegetation of the coastal waters

The effect of the increasing supply of nutrients to the closed coastal waters is an increased amount of plankton algae, but also to a great extent – even in areas of good water replacement – as changes in the rooted vegetation. Perennial algae and rooted plants will, with increasing input of nutrients, gradually succumb to fast growing annual algae or they will die in the shadow of an increased amount of plankton algae, which reduce the penetration of light in the water. The deep range of the vegetation is reduced, because the growth of annual algae and plankton algae is favoured at the expense of other forms, if the input of nutrients increases during the summer. Regarding well-rooted plants, studies have shown that their occurrence and production as a whole are reduced by increasing inputs of nutrients.

In Danish coastal waters a connection has generally been found between the concentration of total nitrogen and the biomass of drifting plankton algae during the summer period. A similar connection with phosphorus concentration has not been found. The effects of reduced light penetration resulting from the larger number of algae shows too in a connection between concentration of total nitrogen and the depth range of rooted plants and of algae, see figure 3.21. Nor has it been possible here to establish any connection with phosphorus, not even in areas with clear indication of phosphorus limitation. It thus seems that the role of phosphorus in the eutrophication of the coastal areas is insignificant (Borum et al. 1990).

In extreme cases, vegetation becomes poor in species with a very limited depth range, it disappears or shows mass occurrence of the annual types of algae known as »algal bloom of brown algae«, »seaweed«, etc. in drifting mats or mats which cover larger parts of the bottom. These mass occurrences create seriously deteriorated conditions for marine bottom animal life, for the breeding grounds and growth possibilities of fish, and even in comparatively low waters they may result in oxygen depletion and occurrence of sulphurous bacteria, »paper white crust«, at the bottom. It makes coast fishing difficult and may mean inconveniences and present unpleasant impressions if washed ashore.

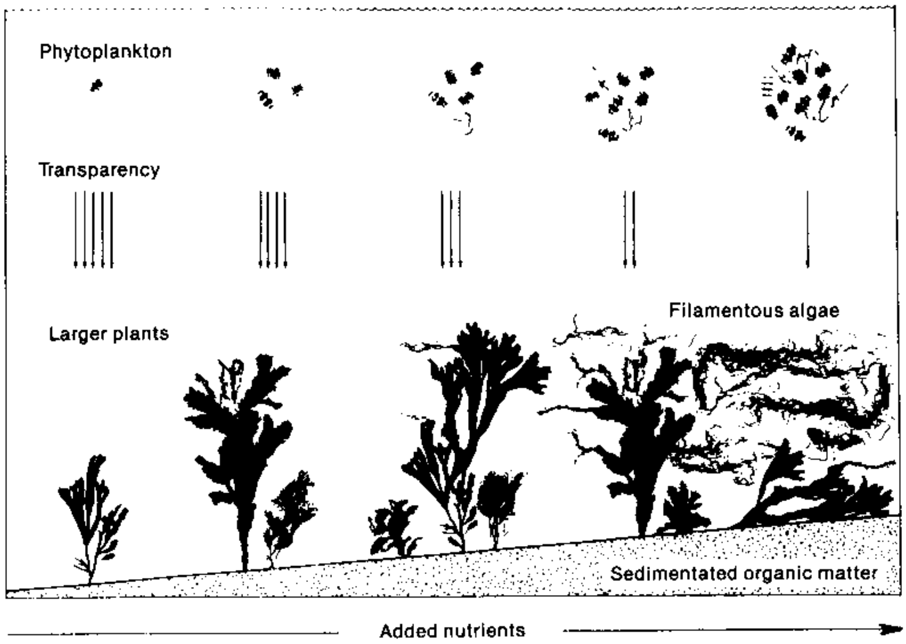

Figure 3.20 **Development in the vegetation of the coastal waters by increased input of nutrients.** (County of Funen 1990).

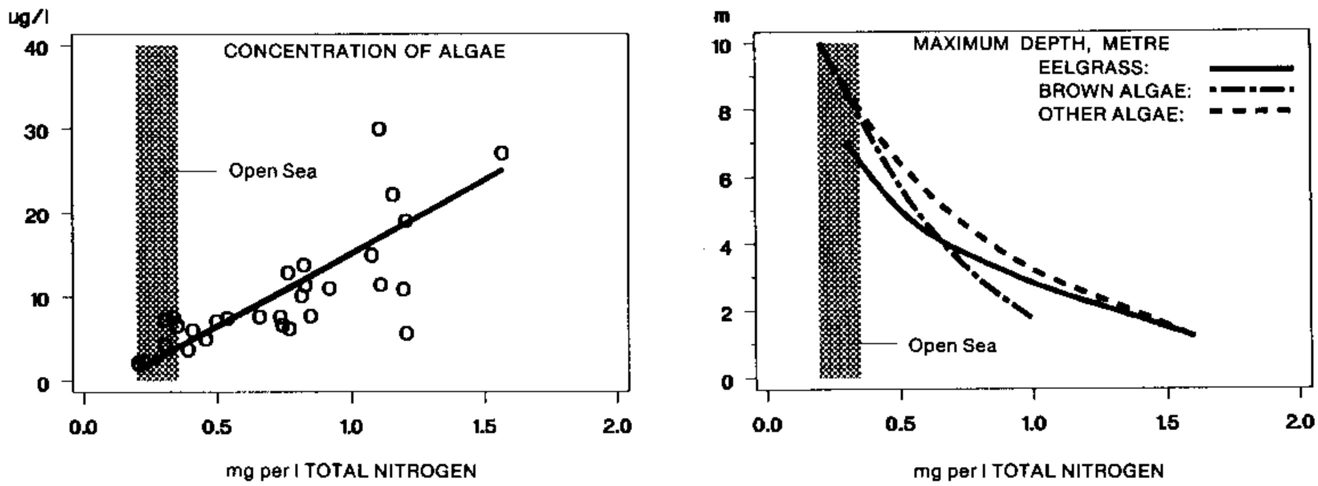

Figure 3.21 **Relation between concentration of nitrogen, concentration of plankton algae and depth range of bottom vegetation** (According to Borum et al. 1990).

The changes in the balance of perennial algae/rooted plants to annual algae and plankton algae may have a reinforcing effect on the deteriorations in the coastal areas. The result of low oxygen concentrations is – in addition to mortality of bottom animals – a possible increase in the release of phosphorus from the sediment. The released phosphate may further increase the growth of algae if nitrogen is still added. As grazing on algae is at the same time decreased as a result of a decline in animals, the major part of the fixed nutrients will again be released to the water masses. Unlike perennial algae, the annual algae are not able to keep the nutrients over longer periods, and the ability of the coastal waters to act as a »filter« against input of nutrients to the open ocean waters is thus reduced.

3.4.7. Quality objectives for marine areas

A main element in the protection of the environmental quality of the coastal waters is the setting up of quality objectives in connection with the county regional planning of the quality of the water areas. The National Agency of Environmental Protection in 1983 (National Agency of Environmental Protection 1983) laid down an objectives system with three principal objectives, in order to avoid a system with many objectives for different types of application and protection. A central point is general objective which presuppose an unaffected or only slightly affected plant and animal life compared with the natural conditions of the individual area. Also there must be a good hygienic water quality, good light conditions, good oxygen conditions and no or only little occurrence of toxic matters in the water, sediment and organisms.

Strengthened objectives

Certain applications or protection considerations necessitates a strengthened objective. The requirements of the general objective will also apply in this case, but may be supplemented by quite specific requirements or requirements of an increased control with the conditions in order to be early to interfere in time in case of unintended influences created by man.

Eased objectives

In locally delimited areas around waste water discharges or other concentrations of activities causing a load on the environment, it has been necessary to accept that the general objective are not in all cases fulfilled. For these areas, if necessary, eased objectives are set up, but with limits for how large effects will be tolerated.

In figure 3.22 are shown areas and localities which are approved or proposed in the regional planning with strengthened objectives and eased objectives, respectively. Where not otherwise indicated the general objectives apply.

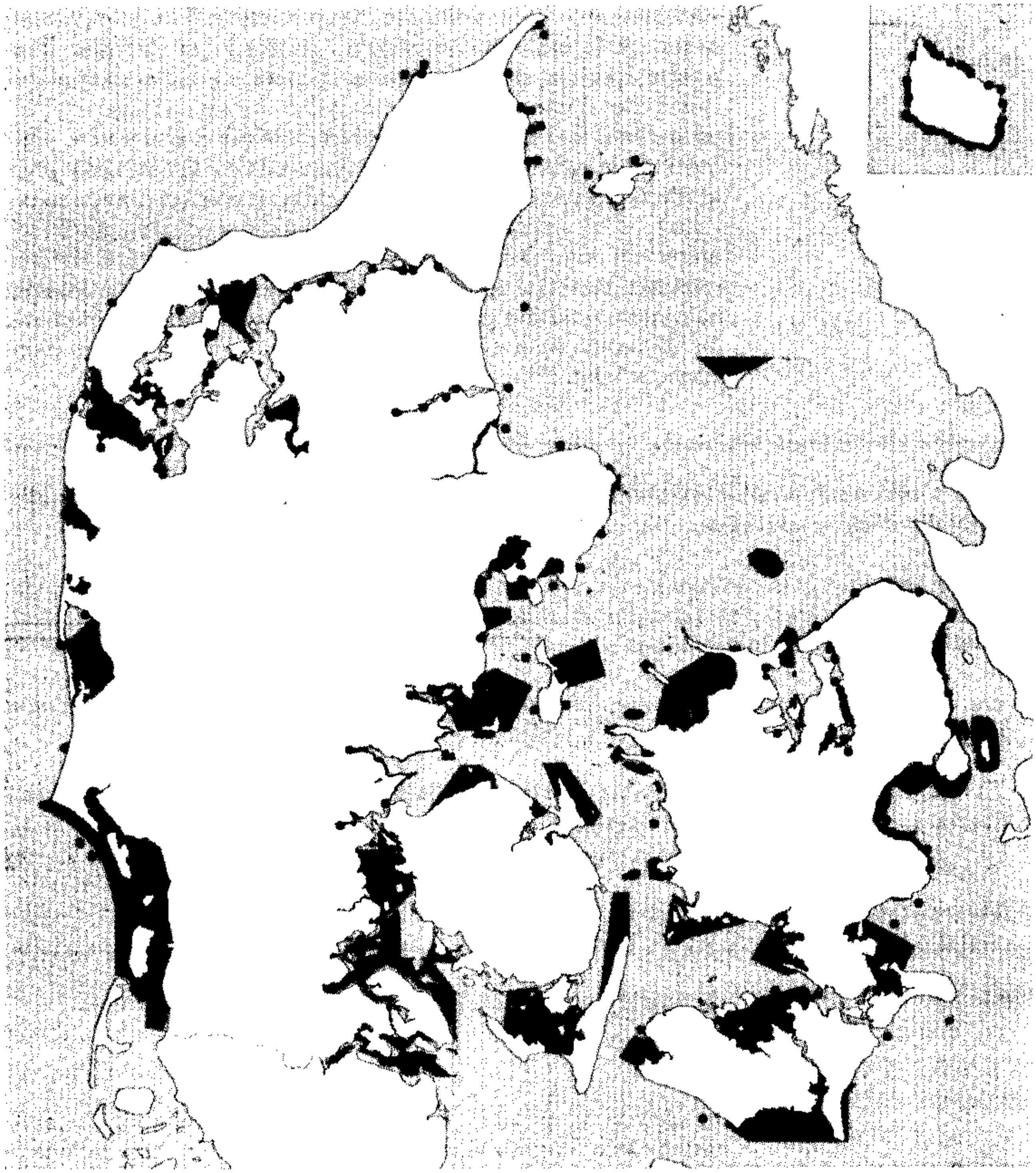

Figure 3.22 **Areas with strengthened and eased objective. Blue: Strengthened. Black: strengthened - natural oxygen deficit. Red: Eased, small localities are shown by an outsized red dot.**

Estimate of the fulfilment of the general objectives

An estimate of the state of the different areas has thus its main emphasis in relation to the reference state, which can be described with the general objectives for the individual area. At the start of the planning of the quality of the coastal waters in the 1970s, it was a precondition that the general objectives in connection with eutrophication had

»automatically« been fulfilled in the open waters. The development in the 1980s has, however, shown that this is not the case. The present deteriorated condition of the open waters, and of many of the closed coastal waters, therefore means that there is no longer any reference basis for the evaluation of the state of the coastal waters. The observed developments in the environmental state and the knowledge of effects of eutrophication, however, makes it possible to make an estimate. In this estimate are included biological conditions and the requirement of no or only weak influence on flora and fauna, and besides the reason for an influence is included. The criteria are still being developed, but general requirements for the general objectives for the coastal waters are used for one or more of the matters mentioned in table 3.5.

- *Plant plankton only occur in moderate amounts and without unnatural mass occurrences, especially not of disturbing or toxic algae.*
- *Bottom vegetation in soft bottoms consist of dense populations of eelgrass with good depth range. On rocks and hard bottoms, algae vegetation shows a natural zoning with good depth range and without unnatural dominance of annual algae.*
- *The animal life of the bottom has many different species with moderate number of individuals of each species and without one-sided dominance of pollutant-tolerant animal groups.*
- *The fish fauna consists of ordinary species such as eel, flounder, dab, cod and trout without abnormal frequency of diseases and without after-taste. There must also be seasonal regular occurrences of herring, garfish and mackerel, and in shallow water of goby and flatfish fry.*
- *The requirements of beach water quality are fulfilled.*

Table 3.5 **Requirements for fulfilment of the general objectives.**

In addition to the above requirements, the condition may be estimated based on physical and chemical parameters: As mentioned, oxygen conditions must be good and unnatural oxygen depletion and formation of hydrogen sulphide must not occur. The level of nutrients and their distribution over the year must not deviate considerably from the conditions in an unaffected background state for the area concerned.

The regional planning lay out the major part of the coastal waters with general objectives. Similarly, the Action Plan for the Aquatic Environment states that the open sea areas shall fulfil objectives which are basically corresponding to the general objectives, but with a strengthened natural scientific objective if possible.

3.5. Forests and natural areas

As mentioned in section 2.1, some of the nitrogen volatilizes in the form of ammonia and are deposited again later. Naturally, this depositing will not only take place in areas from which the volatilization takes place, but also in other water and land areas. In natural areas the depositing of nitrogen with precipitation is probably about 10 kg per ha per year (Hovmand 1990).

Hereto comes that some ammonia may be settled as dry deposit. This amount is dependent on the nature of the surface and is therefore difficult to measure, but it may be estimated to be a few kg N per ha per year. In forests with a »rough« surface it is assumed to be above this average.

3.5.1. Forests

The removal of nitrogen by sale of wood varies somewhat, according to sort of wood and rotation time, but it will often be about 10-12 kg/N per ha per year (Fiedler et al. 1973). The precipitation input of approx. 10 kg N plus dry deposition is therefore sufficient to cover the nitrogen requirement of wood production.

Growth progress

In many forests on land poor in nutrients, a growth progress has therefore been seen compared to previously in the century, and the forest floor flora has become more nutrient demanding.

If the nitrogen is not absorbed by the plants, it may be accumulated in the organic matter (this is true until a certain level), or it may be leached.

The leaching takes place as nitrate. If the nitrogen is deposited from the atmosphere in the form of ammonia, is must be decomposed in the soil to nitrate. This decomposition process with subsequent leaching brings about an increase in the number of hydrogen ions, i.e. an acidification takes place.

Acidification

Most Danish soils have buffer systems which counteract the acidification, but in some places the buffer system may be missing and the soil becomes so acid that the tree roots are damaged.

3.5.2. Heaths, marshes and raised bogs

Heathlands are developed on starved soils and the plants found here will die if the nutritive content in the soil increases. As the deposition of nutrients with precipitation has increased during the latter half of this century, this may lead to a change in the soil and in the flora composition in the heathlands.

Hereto comes that the plants of the heathlands, which are especially adapted to nitrogen poor conditions, are probably effective in assimilating nitrogen compounds from the air, and the dry deposition of ammonia may therefore be larger than on arable land.

Marshes and raised bogs are two different types of bogs poor in nutrients. Marshes develop in areas where the bogs get their water from poor soils. Raised bogs do not have any connection to the ground water, but get all their water and their nutrients with precipitation.

Change in vegetation

In both cases an increased nutritive content in the precipitation will lead to changes in the flora composition, most in high bogs which get all their water and nutrients from precipitation. An enrichment in nutrients (eutrophication) of the soils around the bog will not mean anything to a high bog, but be of great importance to a marsh.

A change has been registered in the vegetation of raised bogs towards more nutrient demanding plants, and this change is most significant in areas with high nitrate and ammonia content in the air (Aaby 1989).

4. Status and Development for input of nitrogen and phosphorus to the aquatic environment

Chapter 2 contains a general illustration of the most important sources of nutrient discharge. Chapter 4 contains surveys of how large the individual sources are today and how they have developed in recent years. Especially emphasized is the development seen in relation to, the adoption of the Action Plan for the Aquatic Environment, which is the main targets of a reduction of the discharges direct to the aquatic environment by respectively 50% for nitrogen and 80% for phosphorus. It is evaluated whether these targets are, or are going to be, reached.

Estimates are made of agriculture's discharges by way of both leaching and volatilization from fields, stables and storages.

Furthermore, the discharges from sewage treatment plants, rainwater discharges, industries, etc. are assessed.

The discharges to the atmosphere from power plants and transportation in Denmark are assessed, as well as the depositing of nitrogen from the atmosphere to land and sea areas. It is especially examined to what degree this deposition is of foreign origin.

4.1. Agriculture

4.1.1. Fertilizer consumption

During the past decades there has been a significant increase in the input of fertilizers to Danish agricultural land. Figure 4.1 shows that especially commercial fertilizers have increased in volume whereas the amount of animal manure has been relatively stable. Through the 1980's, the increase stopped and the input of fertilizers stabilized.

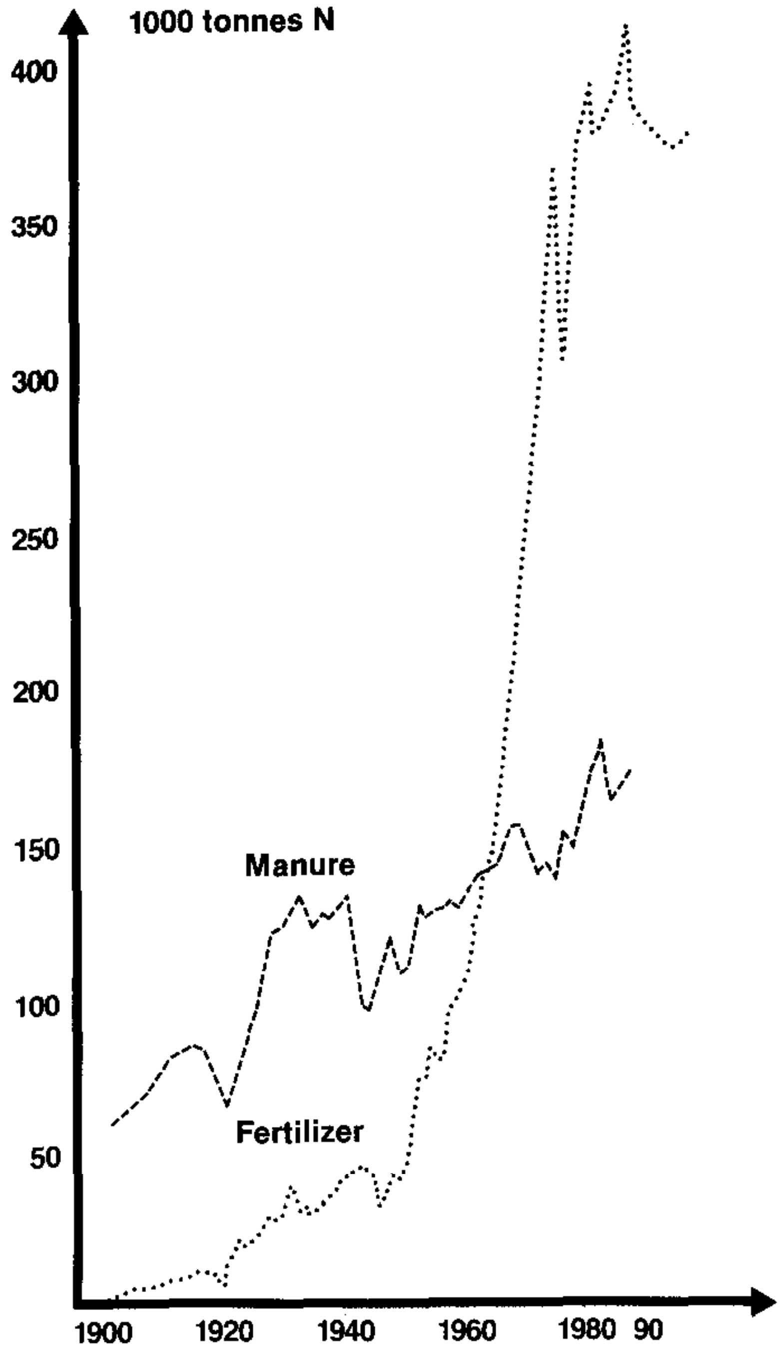

Figure 4.1 **Consumption of commercial fertilizers and animal manure during the period 1900-89** (in part according to Jensen & Reenberg 1986 and Danmarks Statistik).

In the 1950's, about 200,000 tons N per year was added to the arable soil, while at the beginning of the 1980's almost 600,000 tons N per year was added. Part of this increase may be explained by the reduction of the area with nitrogen fixing clover and grass crops. To this can be added a certain increase in crop yield, from about 130 million to about 155 million crop units, during the same period (Ministry of Agriculture 1986). In spite of this, the increased fertilization has led to strongly increasing nitrogen losses to the environment.

4.1.2. **Ammonia volatilization**

As mentioned in Chapter 2.1, animal manure is by far the largest source of ammonia volatilization from Danish farming. In the following the loss nation-wide is assessed for the individual steps in the handling of animal manure, i.e. the loss from stables, manure storages, and the loss in connection with spreading of manure.

Fertilizer production

In Denmark, a little less than 40 million tons of animal manure were produced in 1989 (Laursen 1989a), having a nitrogen content ex animal in the order of 330,000 tons N (Sibbesen 1990).

Some animals graze in the summertime, and about 30,000 tons N is therefore left in the fields in droppings of these animals (Rude 1987). It is estimated that 3-7,000 tons N of this amount is volatilized or on average about 5,000 tons N (Sommer and Christensen 1990).

Stable loss

Of the about 300,000 tons N produced in the stables in 1989, it is estimated that 9-13,000 tons N volatilize directly, or about 11,000 tons N on average (Pedersen and Takai 1987). This figure is relatively small compared with results of similar studies on losses from stables.

Loss from manure slurry tanks

A little more than 60 per cent of animal manure was handled as slurry in 1989. The ammonia volatilization from the slurry tanks in Denmark is calculated to be between 2,000 and 5,000 tons N nationwide. The calculation was made on the basis of the size of the entire slurry the surface in 1989, a total of 3.7 million m^2 (National Agency of Environmental Protection 1990d). Of this, the major part was covered by floating covers which significantly reduce losses (Sommer 1990b).

Loss from liquid manure and solid manure

The remaining about 40 per cent of the animal manure was in 1989 handled as solid manure and liquid manure. Based on knowledge of the ammonia content in urine and the percentage ammonia loss (Sommer 1990b and the National Agency of Environmental Protection 1984b), the loss at storage of urine can be calculated to 1,000 tons N if all tanks are presumed tight. However, it must be expected that a certain number of leaky tanks exist, and the loss may possibly come as for as 10,000 tons N. The loss at storage of solid manure may be estimated to 5-10,000 tons (National Agency of Environmental Protection 1984b and Kofoed & Hansen 1990).

Total loss from stables and storage

In 1989 total loss from stables and manure storages may therefore be estimated to 17-38,000 tons N - or about 28,000 tons N on an average - with about 11,000 tons N from stables and about 17,000 tons N from storage, according to table 4.2.

Losses from spreading

The loss incurred in connection with the spreading of slurry (with the practice of ploughing in, which is assumed to apply in 1989) may be calculated to 13-34,000 tons N. The loss in connection with spreading of urine is estimated to 4-8,000 tons N, and the loss in connection with spreading of solid manure to about 2-4,000 tons N per year. In 1989, the total loss in connection with spreading animal manure was thereby 19-46,000 tons N, or an average of about 32,000 tons N (According to Sommer & Christensen 1990).

	Slurry	Solid manure	Urine
Storing	2–5	5–10	1–10
Spreading	13–34	2–4	4–8
Total	15–39	7–14	5–18

Table 4.1

Estimated total ammonia loss in 1989 in connection with handling of animal manure in the form of manure slurry, urine and solid manure. In thousand tons N.

In the below table the ammonia volatilization is summarized nationwide. Total volatilization, from the manure is produced and until it is ploughed into the soil, is estimated to be about 65,000 tons N, with an uncertainty of 17,000 tons.

Loss from:	Thousand tonnes N
Stables	11 ± 2
Storages	17 ± 8
Spreading	32 ± 14
Grazing	5 ± 2
Total	65 ± 17

Table 4.2

The average nitrogen loss in 1989 from animal manure in stables, storage, by spreading and by grazing. In thousand tons N.

This figure is smaller than the emission values of just over 100,000 tons N which are used in EMEP-model computations (Iversen et al. 1990) and in the model calculations of ammonia deposition in Denmark (Asman 1990). Part of this discrepancy may be explained by the fact that the model calculations use older presumptions about ploughing - in practices, whereby the spreading loss is overestimated. But it is also possible that the stable and storage loss in table 4.2 is underestimated, see section 4.1.6.

4.1.3. Waste water from farms

In addition to losses by way of ammonia volatilization, there are occurrences of leaking of black liquid and urine from stables and manure storages and of silage effluents from silage of green fodder, known as the »waste water from farms«. Originally, the »waste water from farms« was estimated to be 60,000 tons N per year (National Agency of Environmental Protection, 1984b). This figure has later been re-estimated and reduced to 20,000 tons N nationwide in 1983/84 (Hansen & Sommer 1987). Investments in manure slurry tanks and consolidated areas for storage of solid manure can be assumed to have reduced this loss to a level of about 5,000 tons N per year, which must be considered as the minimum obtainable in practice.

4.1.4. Denitrification

A calculation of the total denitrification in agriculture is subject to great uncertainty, especially for areas where fertilization includes large amounts of animal manure.

In the calculation of the denitrification on a national basis, types of soil are divided into two categories, i.e. coarse sand soil and other soils. Besides, areas are included which are solely fertilized by commercial fertilizers and areas where animal manure is spread in the spring or autumn too. On the basis of a number of measurements (e.g. Lind et al. 1990; Pain & Thompson 1989), the following average levels can be set up for the denitrification (Table 4.3).

	Fertilizer	Animal manure (Applied in autumn)	Animal manure (Applied in spring)
Coarse sand	1–2	1–10	1–5
Other soils	10–20	30–60	20–40

Table 4.3 **Denitrification in kg N per ha per year as function of type of soil and input of fertilizer.**

Based on an average of the figures in table 4.3, the denitrification may be estimated on a national level. From the about 0.8 million ha coarse sand soils about 2,000 tons N is lost. For the other soils concerned, the loss from the about 1 million ha commercially fertilized fields is about 15,000 tons N and from the about 1 million ha animal manure fertilized soils, the loss is about 40,000 tons N (assuming that

0.5 million ha is fertilized in the autumn and 0.5 million is fertilized in the spring). Total denitrification can thus be estimated to be up to 60,000 tons N per year.

4.1.5. Nitrogen leaching

Leaching of nitrogen varies quite considerably depending on the actual fertilizing practice, type of soil, climate and rotation of crops, etc. A direct determination of total leaching from arable soil therefore in principle requires knowledge of such conditions in all of the about one million fields in Denmark. Of course, this is impossible and it is necessary to generalize on the basis of available measurements, supplemented with statistical information about management practise.

Measuring of leaching in test fields

As mentioned in section 2.1.2, the Danish Research Service for Plant and Soil Science has carried out a great number of measurings of leaching, with great variations, and with an average level in the order of 55-70 kg N per ha per year. If these results are scaled up to cover the entire country, a leaching level in the order of 160,000-200,000 tons N per year is reached.

Leaching measuring from practical farming

Leaching measurements from practical farming made in connection with the NPO – research programme (Hansen 1990c), show a higher nitrate leaching than found in the experimental fields, probably as a result of a less optimal distribution of animal manure, over-fertilization, etc.

The measuring period from 1986-1990 is relatively short and characterized by a number of unusually mild winters with high nitrogen mineralization. Also precipitation conditions have been unusual, but based on measurements of nitrogen runoff in watercourses, see figure 5.12, there is no reason to assume that the nitrogen leaching of the period was above normal.

Leaching measurements may roughly be divided into two groups. One group comprises farms with optimum operation practices, where commercial fertilizers and animal manure are spread during the spring. Here, from winter green fields, the leaching is in the order of 40-50 kg N per ha, while from fields without plant cover in the autumn the leaching is 50-70 kg N per ha.

Nitrogen leaching by over-fertilization

The other group comprises the part of the fields in practical farming which are over-fertilized. Here the plants do not have time to take up the available nitrogen during the growth period. The excess nitrate may therefore be washed out during the autumn. To this comes leaching from animal manure spread during the autumn. Under unfavourable conditions this may be leached totally. Such fields leach from 70 and sometimes up to 180 kg N per ha per year (Hansen 1990c).

On this basis alone it is difficult to estimate exactly the nationwide leaching. This requires a further in-depth statistical analysis of the actual farming practice (as it is e.g. carried out in connection with the nationwide leaching calculations described below). But on the basis solely of the measuring, a general estimate of an average leaching of 70-80 kg N per ha does not seem to be overestimated. To this comes a contribution of organic nitrogen amounting to about 10% of total leaching (Gustafson, personal comments and B. Hansen 1990c). The average annual leaching from Danish arable soil may therefore on this basis be estimated to about 80 kg N per ha, corresponding to about 220,000 tons N per year.

Model calculation of leaching

Alternatively, the relatively few leaching measurements can be used to develop a calculation model for the leaching. If such a model can calculate leaching in accordance with measurements, it is possible to make a number of calculations of the most common farming practices, and then sum up to cover the country by means of statistical information.

Leaching calculated by DAISY

Under the NPO research programme, such a leaching model, DAISY has been developed (Hansen et al. 1990). The reliability of the model has been checked against both Danish and foreign data and it appears to give rather good estimates of the leaching.

Generally, it should, however, be pointed out that DAISY overestimates plant production and thereby plant nitrogen uptake, as only water and nitrogen are included as growth limiting factors. In practice, also other factors, such as plant diseases, attacks by pests and deficiency of other nutrients, limit plant production. This means that the model calculations by virtue of an overestimated plant production leave relatively little nitrogen in the soil, which is why the calculated leaching becomes smaller than the actual one. (Vereecken 1990).

A detailed leaching calculation for Denmark as a whole has been made by the help of the model DAISY for the period 1987-90 (Nielsen et al. in press.). The model calculations were based on a statistical material about the use of commercial fertilizers and animal manure, and actual rotation of crops, collected by the Plant Directorate.

Denmark was divided into five regions, within which variations in climate, soil conditions and farming practices was taken into account. In Table 4.4, the annual leaching is stated for each region and for the entire country. It should be noted that the calculation only comprises nitrate-nitrogen, i.e. the loss of organic nitrogen is not included.

As small farms are under-represented in the data basis, and since some of these farms have a high-density of livestocks, the leaching will be underestimated. This, in combination with the above mentioned underestimation of the leaching, as a result of an overestimation of the plant production, means that the model must be considered systematically to underestimate the leaching, probably by about 10%.

	West Jutland	North Jutland	East Jutland	Funen	Zealand mm	Denmark
1986/87						
Leached t nitrogen	72.000	24.000	28.000	9.000	12.000	144.000
Leached kg N per ha	67	59	56	37	20	51
1987/88						
Leached t nitrogen	87.000	40.000	42.000	16.000	31.000	216.000
Leached kg N per ha	81	99	87	68	52	77
1988/89						
Leached t nitrogen	68.000	24.000	21.000	11.000	12.000	136.000
Leached kg N per ha	64	58	45	46	19	49
1989/90						
Leached t nitrogen	76.000	30.000	29.000	16.000	29.000	181.000
Leached kg N per ha	71	76	61	70	49	65

Table 4.4 **Calculated nitrogen leaching from arable soils in Denmark. In thousand tons nitrate-N per year. The figures are not adjusted for systematic faults in the calculations.**

The table shows that there were great variations in the nitrogen leaching, both from one year to another and from one region to another. Based on the figures of the table, the annual average leaching for the period was 170,000 tons nitrate-N. As previously mentioned the model underestimates the leaching by around 10%, which gives an adjusted leaching figure of about 190,000 tons nitrate-N. To this must be added, as previously mentioned, an organic nitrogen contribution of about 20,000 tons N per year, leading to an average leaching for the country as a whole, according to the model calculation, of about 210,000 tons N per year during the period 1987-90.

Model calculations of the nitrate content of the ground waters has been carried out in the sandy Karup stream catchment area in Jutland and the clay Langvad stream catchment area in Zealand (Storm et al. 1990). For the decade 1979-88, an average annual leaching of 81 kg nitrate-N per ha has been found for the rotation of crops in Karup, and for Langvad stream an average leaching of 43 kg nitrate-N per ha was found. The calculations prove to be in conformity with observations of the nitrate content in ground water.

If it is assumed that the Karup and Langvad figures are representative of each of their halves of the arable soil, a weighted leaching average for the country as a whole is found to be around 62 kg nitrate-N per ha, or a total leaching of around 175,000 tons nitrate-N per year. To this is again added the adjustment for the underestimate of the model and the organic nitrogen contribution, and total leaching then reach a figure of around 215,000 tons nitrogen per year. It can be seen that this figure is in conformity with the calculations above.

Check of the leaching calculations

The calculated nitrogen leaching from the arable soils can be checked by means of measurements in ground water and watercourses.

The Geological Survey of Denmark maps the nitrate content in the upper ground water levels. In the sandy areas in Jutland this mapping shows general levels of 100-150 mg nitrate per liter. If a net precipitation (precipitation drawback the evaporation) of about 350 mm is assumed, these values can be converted into a nitrogen percolation of 80-120 kg N per ha, by means of simple calculations taking into account the dilution of soil nitrate. There are no similar recent data for the upper ground water under the clay soils on the islands, but an older study of the nitrate content in wells on the islands (where the net precipitation is considerably lower) showed nitrate concentrations of an average of 130-150 mg nitrate per liter (Christensen 1970). This corresponds to very considerable leaching values. Although part of it may probably be referred to as local pollution, it is a clear indication that in the islands too a significant leaching of nitrogen takes place. There is thus conformity with the leaching figures mentioned above and the resulting nitrate concentrations in the upper ground water.

In connection with the monitoring programme, the total nitrogen runoff to the sea from the Danish watercourses has been calculated to 65,000 tons N for the year 1989. The runoff in 1989 was unusually low, and the runoff in a normal year may be estimated to 110,000 tons N (Kristensen et al. 1990b). Lakes and wetlands may remove considerable amounts of nitrogen by denitrification (Jeppesen et al. 1990, Brüsch et al. 1990). In ground water reservoirs a considerable denitrification takes place too (Storm et al. 1990 and Jacobsen et al. 1990). An estimate of total denitrification makes it reasonably likely that the leaching from arable soils must be at least 200,000 tons N in a normal year.

Total leaching

The different methods of calculating the nitrogen leaching shows that for the country as a whole it can be assumed to have been about 210,000 tons N per year on an average for the period 1987-90.

4.1.6. Collocation of the items in agriculture's nitrogen accounts

In order to obtain a control of the calculated values for agriculture's nitrogen leaching, »nitrogen accounts« have been made on farm and field level, respectively. These accounts must tally (within the uncertainty), if the above mentioned independently determined estimates of the different loss items are to be considered reasonably certain. The accounts have been made as an average for the period 1988-89.

The input/output of animal production is illustrated in table 4.5.

Input		Output	
N in fodder	425	Animal products	95
		Grazing animals	30
		Stable and storage loss	30
		Waste water from farms	5
		Field applied manure	205
Total input	425	Total output	365

Table 4.5

Average value for the annual nitrogen flows on farm level in thousand tons N per year in the period 1988-89. (figures are rounded off to whole 5,000 tons).

Fodder consumption and the animal production are determined based on information from Danmarks Statistik. The N-content in the fodder and in the animal production is determined on the basis of average values for the N-content in the respective products (Sibbesen 1990 and Nielsen 1990). The fodder consumption is given as the net input to animals and does not contain a conservation loss, calculated to be 15,000 tons N (Laursen 1989).

The amount of manure produced by grazing animals is calculated (Rude 1987). The losses from stables and storages are mentioned in section 4.1.1. The »waste water from farms« is mentioned in section 4.1.3. The amount of manure available for field application (the ex storage manure) is calculated in accordance with current standard figures (Laursen 1989).

The farm accounts do not tally, and the deviation of 60,000 tons N per year may be due to uncertainty of the calculation of the N-content in fodder and animal production, and to uncertainty of the individual loss items. It might be that a certain loss occurs by denitrification from dung heaps, but in particular it cannot be excluded that the ammonia loss from stables is underestimated.

The calculation of the amount of N in manure ex storage is uncertain too. If it is assumed that the deviation in the accounts stems from this item, the amount must be presumed considerably higher than indicated by the standard figures. Direct measurements of N in manure, however, give no indications that the standard figures are too small. It is necessary, therefore, to improve the knowledge of the nitrogen content in the manure ex storage.

The field account is outlined in Table 4.6.

Input		Output	
Fertilizer	390	Harvested crops	360
Fieldapplied		Ammonia volatilization	30
Animal manure	205	Denitrification	60
N-fixation	30	Leaching of nitrate-N	190
Precipitation		Leaching of organic-N	20
and dry deposition	60	Incorporation in soil	
Waste water and sludge	5	organic matter	25
Grazing animals	30	Ammonia loss	
		from grazing animals	5
		Loss by ammonia-digestion	
		of straw	10
		Loss by burning of straw	10
Total input	720	Total output	705

Table 4.6 **Average value for the annual nitrogen flows on field level in thousand tons N per year in the period 1988-89. (figures are rounded off to whole 5,000 tons).**

The consumption of commercial fertilizers is computed by Danmarks Statistik, and the amount of animal manure appears from Table 4.5.

The input via the biological nitrogen fixation is calculated on the based on the area with peas, alfalfa and clover and the nitrogen fixation of these crops per ha.

Deposition of nitrogen compounds with precipitation and by dry deposition is estimated to just under 21 kg N per ha, see section 2.7.

Waste water and sludge from industry and local treatment plants are to a certain extent used as fertilizers in the fields. This waste contains about 5,000 tons N (Nielsen 1990).

The nitrogen content of harvested crops is calculated based on information from Danmarks Statistik on the size of the harvest yield and the average N-content in the different crops (Nielsen 1990).

The ammonia volatilization from the spreading of animal manure is estimated on the basis of the figures in section 2.1.3. The ammonia volatilization from commercial fertilizer, plants and directly from the soil are considered insignificant, and these losses are therefore not included in the N-account.

The denitrification loss of 60,000 tons N comprises losses by way of free nitrogen (N_2), and losses by way of nitrogen oxides N_2O and NO. The nitrogen oxides constitute a very small part of the denitrification loss, and these gasses are therefore not interesting as a quantitative item in the N-accounts, but they are of course interesting as contributors to the green house effect.

It is very difficult to asses changes of the nitrogen layer in the soil humus pool. Based on the present extensive use of animal manure and green fields, an average increase of about 10 kg N per ha is assumed. Finally, losses in connection with burning and ammonia lixivition of straw are included (about 15.000 tons N) (Laursen 1989).

It can be seen that in the field account good accordance between total input and total output of nitrogen is obtained.

In tables 4.7 and 4.8, the different losses from farming are collated, as they are estimated as annual averages – for the period 1988-89. The figures are estimates and therefore subject to uncertainty.

Loss to groundwater and streams	
Waste water from farms	5
Leaching from the fields	210
Total leaching	215

Table 4.7 **Estimate of agriculture's average nitrogen loss in thousand tons N per year to the aquatic environment during the period 1988-89. The figures are rounded off to nearest 5.000 tons.**

Loss to the atmosphere	
Stable- and storageloss and loss from grazing animals	35
Loss due to field application	30
Loss from ammonia digested straw	30
Total ammonialoss	75
Straw burning, preservation	20
Total volatilization	95

Table 4.8 **Estimate of agriculture's average nitrogen loss in thousand tons N per year to the atmosphere during the period 1988-89. The figures are rounded off to nearest 5,000 tons.**

4.1.7. Reduction of leaching as a result of changes in farming practises.

The NPO Action Plan and the Action Plan for the Aquatic Environment

With the NPO Action Plan and the Action Plan for the Aquatic Environment, a number of initiatives were taken, the purpose of which was to reduce the nitrogen losses to the aquatic environment by 50%. The main objective of these initiatives is to ensure a better utilization of the nutrients in animal manure and thereby to reduce nitrogen leaching. A better utilization of animal manure will, moreover, result in a smaller requirement for nitrogen fertilizers, whereby it will be possible to reduce the consumption of commercial fertilizers.

The most important initiatives are the requirements of increased storage capacity for animal manure and of a systematic fertilization planning, which shall ensure that fertilizers are used at the right time and in the right amounts. Furthermore, requirements were introduced to establish green fields in the autumn in order to reduce the nitrogen leaching in autumn and winter.

In the following sections, the changed practises until now concerning the time of spreading animal manure and the total amount of nitrogen added will be evaluated. Also, the changes in crop structure, including green fields, will be shown with a view to illustrating the importance of these changes for the nitrogen leaching from the beginning of the 1980's till the end of the 1980's. It must be noted that these effects are evaluated before the full implementation of the Action Plan for the Aquatic Environment.

Besides, a description is made of how the consumption of commercial fertilizers may be used as a barometer of how well animal manure is utilized. Effects of planned and implemented structural initiatives, such as extensification, fallowing and classification of environmentally sensitive areas, are mentioned in brief, although they have not yet had any impact on the leaching.

Leaching calculated with DAISY

The leaching calculations in the following chapters are based on the root zone model DAISY (Hansen et al. 1990), and the changes in the leaching have been calculated based on a very simplified crop structure, wherefore the results are subject to uncertainty. In the interpretation of the leaching figures, it is necessary also, as mentioned before, to make a number of reservations. On the one hand, the production limitations entered in DAISY will in principle lead to an overestimation of plant growth and thereby also of N-intake, which again results in a underestimation of leaching. On the other hand, the calculations do not include the ammonia volatilization by the spreading of animal manure which should imply a certain overestimation of the leaching.

The figures calculated for the leaching of nitrogen per ha, which are used below, are therefore lower than the measured figures, and they therefore underestimate the leaching level.

Since the purpose of the following sections are solely to compare changes and not absolute levels, the figures calculated are adequate for indicating trends in developments of the leaching.

4.1.8. Effect of spring versus autumn spreading of animal manure.

Nitrogen, especially in liquid manure, is best utilized when spread in the spring. Thus it is necessary with a storage capacity in order to enable the spread of manure solely during spring.

Leaching losses as a result of autumn as compared to spring application are illustrated by leaching models for one actual crop rotation.

Leaching from rotation of crops

The leaching is calculated for a normal simplified rotation of crops consisting of winter wheat - beet - spring barley with undersown grass - grass - spring barley. Normal amounts of fertilizers have been given to the crops by way of manure, supplemented at different times by commercial fertilizers in the spring at the recommended standards.

The results of the different inputs of animal manure, alternatively in the autumn, half autumn + half spring and in the spring can be seen in figure 4.2, in which is also shown the effect of a pure commercial fertilizer spreading in the spring.

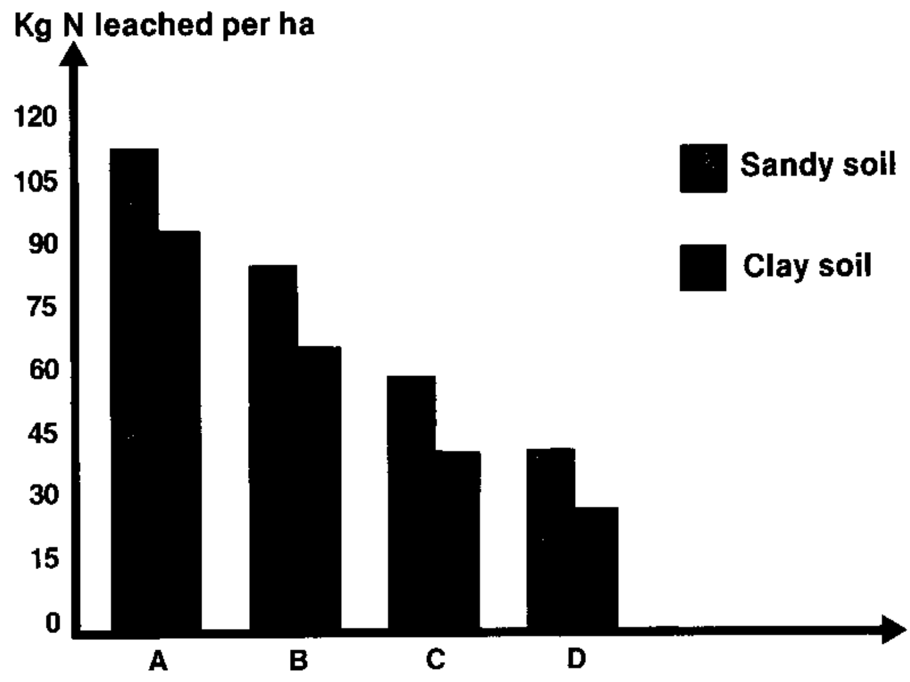

Figure 4.2

Nitrogen leaching from a rotation of crops consisting of winter wheat - beet - spring barley with lay out - grass - spring barley. The rotation of crops has received the following fertilizer distributions: A. animal manure autumn, B. animal manure half autumn + half spring. C. animal manure spring and D. commercial fertilizers spring. The calculations have been made by DAISY with climatic data for the last 20 years for a sandy soil (JB3) and a clay soil (JB7), respectively, (Styczen 1990).

Leaching reduction

From figure 4.2, it can be seen that leaching for the rotation of crops in question can be reduced by about 50 kg N per ha on both sandy and clay soils by spreading liquid animal manure in the spring instead of in the autumn. It should be noted that the above leaching reduction is somewhat less in case of solid animal manure, where the liberation of nitrogen takes place over a longer period of time (Johnsson 1990).

Storage capacity

The possibilities of spreading animal manure in the spring have increased concurrently with the establishment of a larger storage capacity for animal manure, as it appears from figure 4.3. It shows that about 75% of the farms fulfilled the requirements of storage capacity in October 1989, whereas in 1987 it was only about 50%. The condition for a more effective animal manure utilization has thus improved, but it does not necessarily mean that the conduct, with regard to when animal manure is spread, has changed.

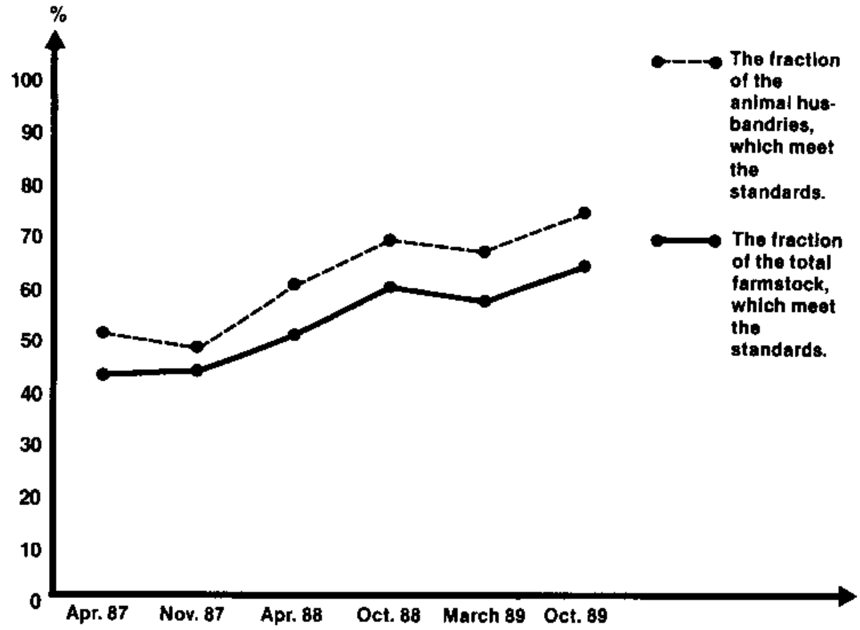

Figure 4.3 **Fulfilment of storage requirements of animal manure expressed as the share of all livestock farms, which fulfil the requirements, and share of total livestock in farms, which fulfil the requirements, respectively.** (Opinion research institute Observa 1989).

The behaviour of the Danish farmers with regard to time of spreading has been studied in seven catchment areas in 1983/1984 and 1989, respectively (Hansen, 1990b). The results of these studies can be seen in table 4.9, from which it appears that only about 7% of the animal manure spread was moved from autumn to spring during the period 1983/84 to 1989.

Season	1983/84 %	1989 %	Change %
Autumn+winter	54	47	÷7
Spring+summer	46	53	+7

Table 4.9 **Time of distributing animal manure in seven watercourse catchment areas in Denmark for 1983/1984 and 1989, respectively. The figures are calculated as a percentage of total amounts of solid manure, liquid manure and manure slurry (Hansen 1990b).**

Based on the information in figure 4.2 and table 4.9 it is now possible to estimate the effect obtained by the better utilization of animal manure, but first the area fertilized with animal manure must be calculated. According to a random sample study by the Plant Directorate (the Ministry of Agriculture 1990) animal manure is spread in Denmark on an area of about 1,100,000 ha. The area now receiving animal manure spring or summer instead of autumn or winter has therefore increased by about 77,000 ha, corresponding to the 7%.

Effect of changed behaviour

If it is presumed that leaching on an average has been reduced by about 50 kg N per ha (see figure 4.2), the total annual leaching reduction as a result of the changed behaviour with regard to the time of spreading may be calculated to just under 4,000 tons nitrogen on a country-wide basis.

The effect of establishing an increased storage capacity for animal manure has thus been very limited until now, due to the modest change in behaviour as regards time of spreading.

This modest change in behaviour may in part be explained by the fact that the Action Plan for the Aquatic Environment was not fully implemented in 1989, as the requirements of storage capacity are not to be fully met until the end of 1992.

4.1.9. Effect of deviations from normal input of fertilizers

Fertilization beyond the optimum level leads to increased nitrogen leaching, and that is why a precise fertilization planning is necessary in which especially the value of animal manure is correctly assessed.

Leaching and over-fertilization

The effect of over-fertilization may be illustrated for selected crops by means of leaching curves as shown in figure 4.4. The leaching curves are calculated by means of DAISY on the basis of four still increasing fertilizer treatments which are in conformity with practice, see figure 4.5. Spring cereals and winter cereals were fertilized only with commercial fertilizers on the three lowest fertilization levels, and only the higher fertilization level include both animal manure and commercial fertilizers. With regard to beet, all fertilization levels include both animal manure and commercial fertilizers. Animal manure for all crops was distributed equally between spring and autumn.

From figure 4.4, it appears that leaching of nitrogen is considerable if large amounts of fertilizers are applied. A good example of a crop which, on account of over-fertilization, gives rise to a large leaching, is beet which have a nitrogen requirement of about 180 kg N per ha. The beet are often given 300-500 kg N per ha of animal manure alone, see figure 4.5 which results in an extremely large leaching of nitrogen.

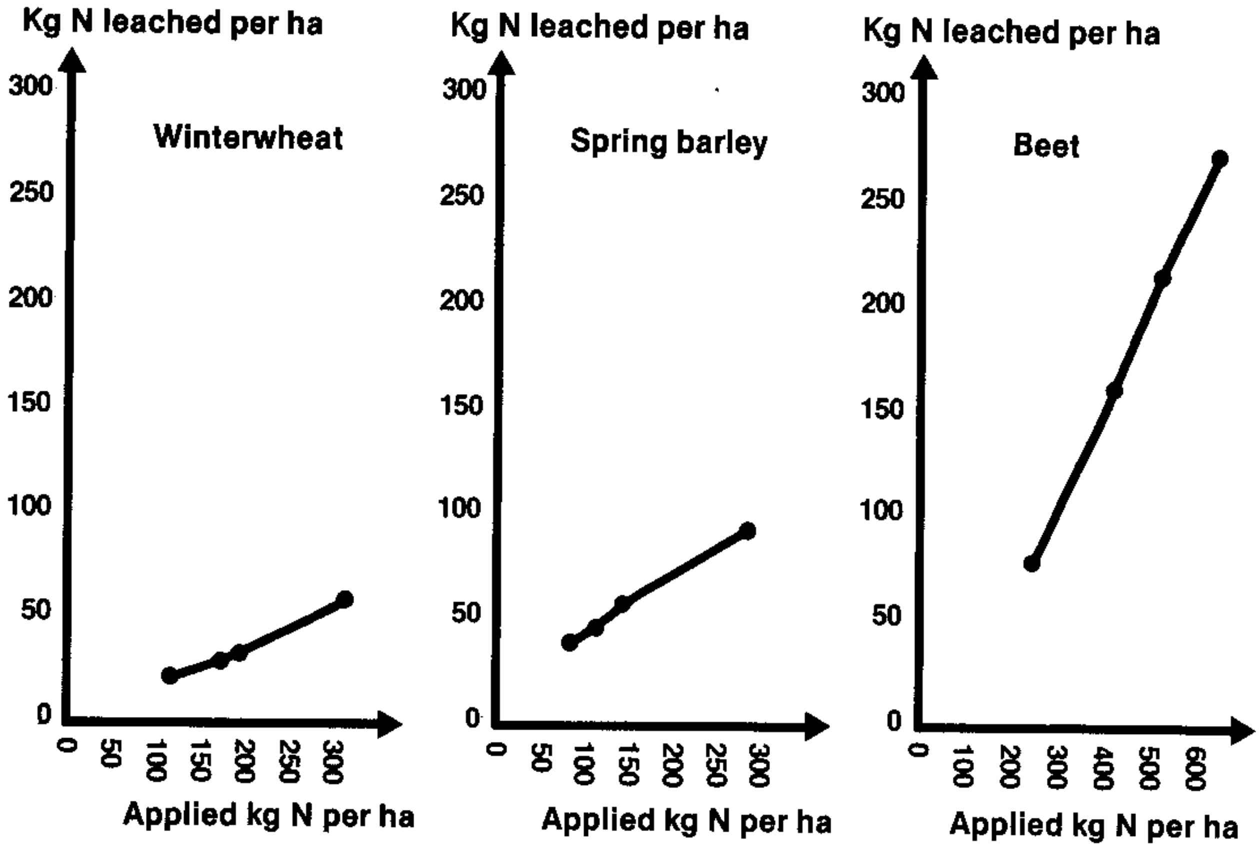

Figure 4.4 **Leaching of nitrogen from winter wheat, spring barley and beet as function of increasing amounts of nitrogen applied. The leaching curves are calculated as a weighted average for clay and sandy soils, where spring barley and beet are weighted with 1/3 clay and 2/3 sand, whereas winter wheat is weighted with 2/3 clay and 1/3 sand, as the winter crops are most often found in clay soils. The calculations have been made by the DAISY model** (Styczen 1990).

In this connection it is interesting to see the course of development in figure 4.5 where the actual input of nitrogen to different crops is outlined for 1983/84 and 1980 (Hansen 1990b).

If comparisons are made between the input of fertilizers in 1983/1984 with the input in 1989, it can be seen that over-fertilization is not as common today as previously. This applies also to under-fertilization. In general, it can therefore be concluded that farmers have become better to comply with the recommended fertilization levels, although there is still a considerable over-fertilization, especially on beet where fertilization with animal manure is still important.

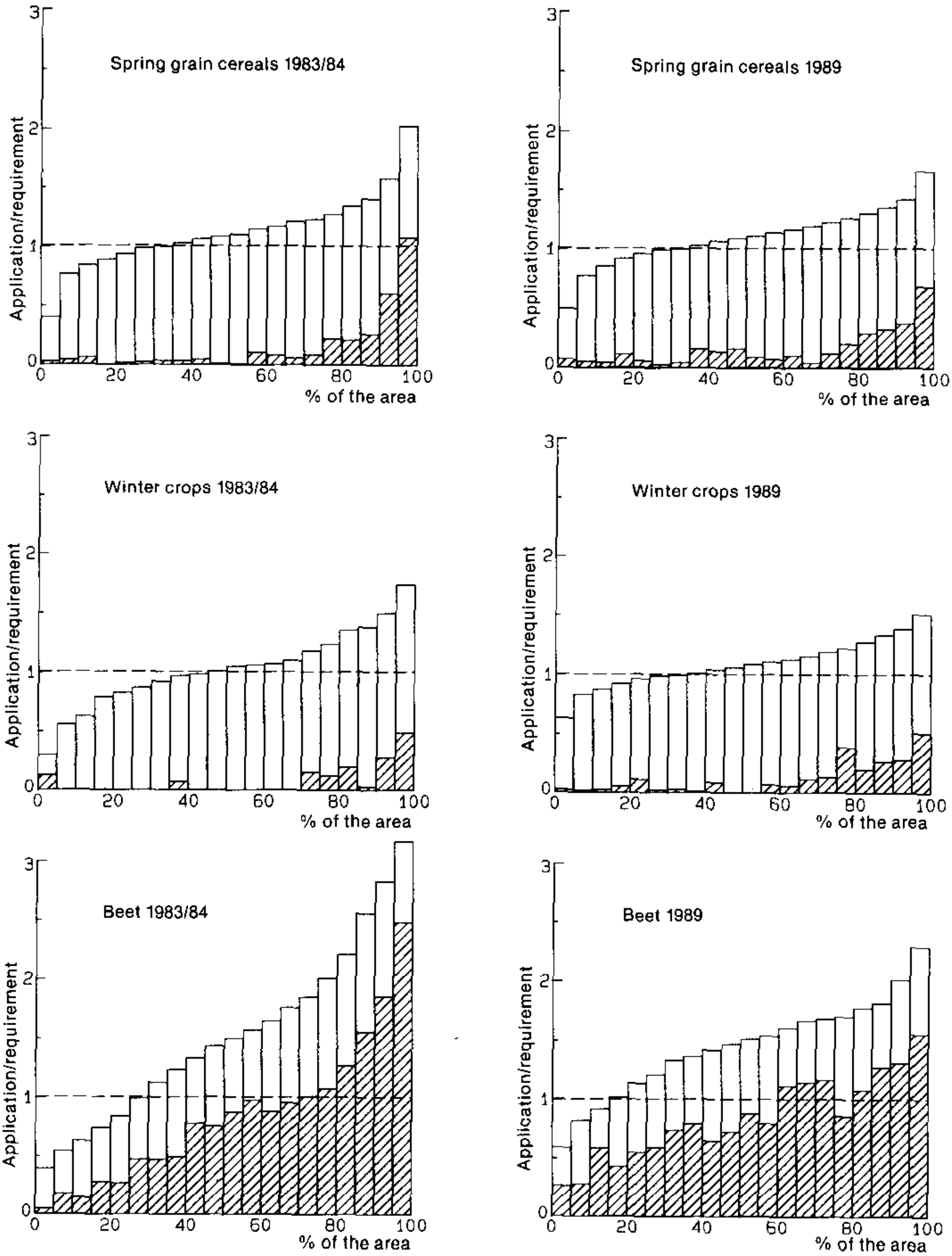

Figure 4.5 **Variations in effective N-input to various crops 1983/1984 and 1989. The hatched part of the columns show the effective N-input in animal manure and the non-hatched part the supply of commercial fertilizers. Broken lines show the average nitrogen requirement of the crops for the years in question** (according to Hansen 1990b).

Changes in leaching

The effect of the changed input may roughly be estimated by calculating the average leaching of nitrogen for the application of fertilizers in 1983/1984 and compare this with the average calculated leaching for the application of fertilizers in 1989. The calculations have been made on the basis of the leaching curves in figure 4.4 and the actual fertilizer levels in 1983/1984 and 1989, respectively, see figure 4.5. In the calculations it is assumed that the leaching curves for winter wheat and spring barley apply in general to winter cereals and spring cereals, respectively. The results appear from table 4.10.

Crop	1983/84 N-leach. Kg per ha	1989 N-leach. Kg per ha	Changed N-leach. Kg per ha	Ha 1989	Change in N-leach. Tonnes
Winter crop	41	41	0	613.100	0
Spring grain cereals	70	60	-10	948.500	-9.500
Fodderbeet	195	215	+20	105.000	+2.000
Total				1.666.600	-7.500

Table 4.10

Change in the leaching of nitrogen as a result of changed distribution of fertilizers from 1983/1984 to 1989 for winter cereals (excluding winter rape), spring cereals (excluding spring rape) and beet. The reduction in the nitrogen leaching is calculated on the basis of the crop distribution in 1989.

From table 4.10 it can be seen that a reduction has taken place in the leaching from spring cereals, whereas the leaching from winter cereals is unchanged. Opposite to what could be expected, leaching from fodder beet has not fallen from 1983/84 to 1989, although over-fertilization was generally reduced. The reason is mainly that in 1989, even at the low fertilization levels, large amounts of animal manure was added to the fodder beet. In spite of this, the reduction of the nitrogen leaching, on the about two-thirds of Denmark's area cultivated with the three crops, can be calculated to about 7,5000 tons N, as a result of an improved fertilization planning, where over-fertilization was reduced but still not eliminated.

4.1.10. Effect of a changed crop structure with more green fields

Not all crops, defined as green fields, take up the same amount of nitrogen during the critical period in the autumn and winter where there is a large leaching of nitrogen.

The difference in nitrogen leaching from selected crops and from a natural area, consisting of continuing grass, without distribution of fertilizers, is illustrated with DAISY calculations in figure 4.6.

The crops have been fertilized in the spring by optimal amounts of commercial fertilizers and only beet have been given animal manure, equally applied autumn and spring. The actual applications of fertilizers correspond to the recommended application of fertilizers. The calculations in figure 4.6 are made for a clay and a sandy soil.

Figure 4.6 shows that the leaching of nitrogen is largest from beet which are often given large amounts of animal manure. Spring barley has the second largest leaching on account of the relatively short growth season, where crops already stop taking up nitrogen at the beginning of July. The calculations also show that winter crops limit leaching just as much as barley with undersown grass. Grass fields in rotation on sandy soils may reduce leaching further, whereas leaching is higher on clay soils, where grass fields are ploughed in the autumn.

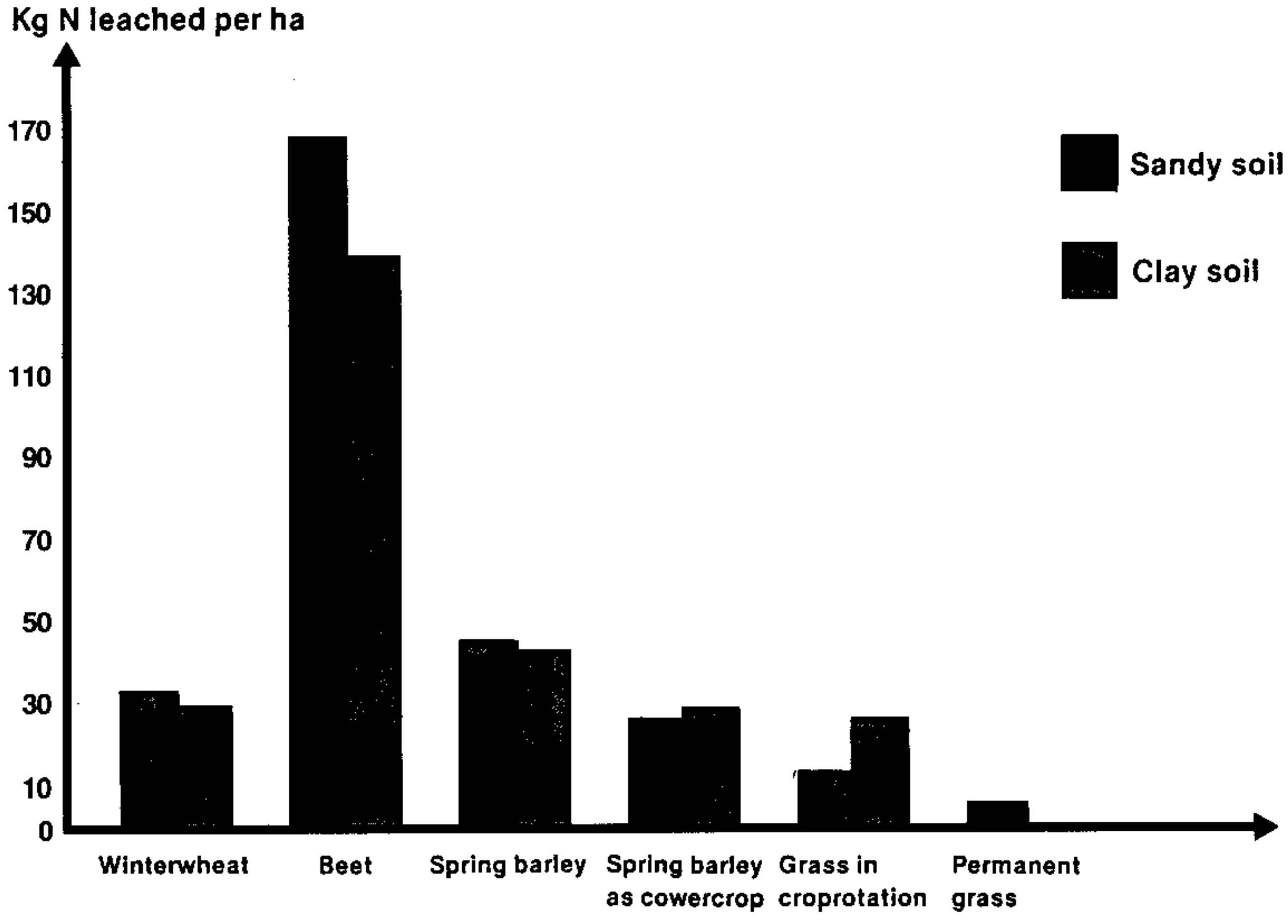

Figure 4.6 **Average N-leaching from winter wheat, beet, spring barley, spring barley undersown with catch-crop, grass in rotation and permanent grass. The leaching is calculated for a clay soil (JB7) and a sandy soil (JB 3). The crops are given fertilizers corresponding to their N-requirements.** (Styczen 1990 and Storm et al. 1990).

Beet give big leaching

The leaching figures mentioned in figure 4.6 gives a leaching from beet which is higher than normally estimated, may be due to the fact that the ammonia volatilization has not been taken into account, whereby a larger N-amount is available for the leaching. The leaching from cereals is considerably lower than normal, which may in part be due to the assumption of optimum fertilization, but also to the fact that DAISY systematically overestimates plant production.

In spite of the above reservations, the actual leaching figures in figure 4.6 can be assumed to be usable for estimating the effects of the changed crop structure as shown in figure 4.7.

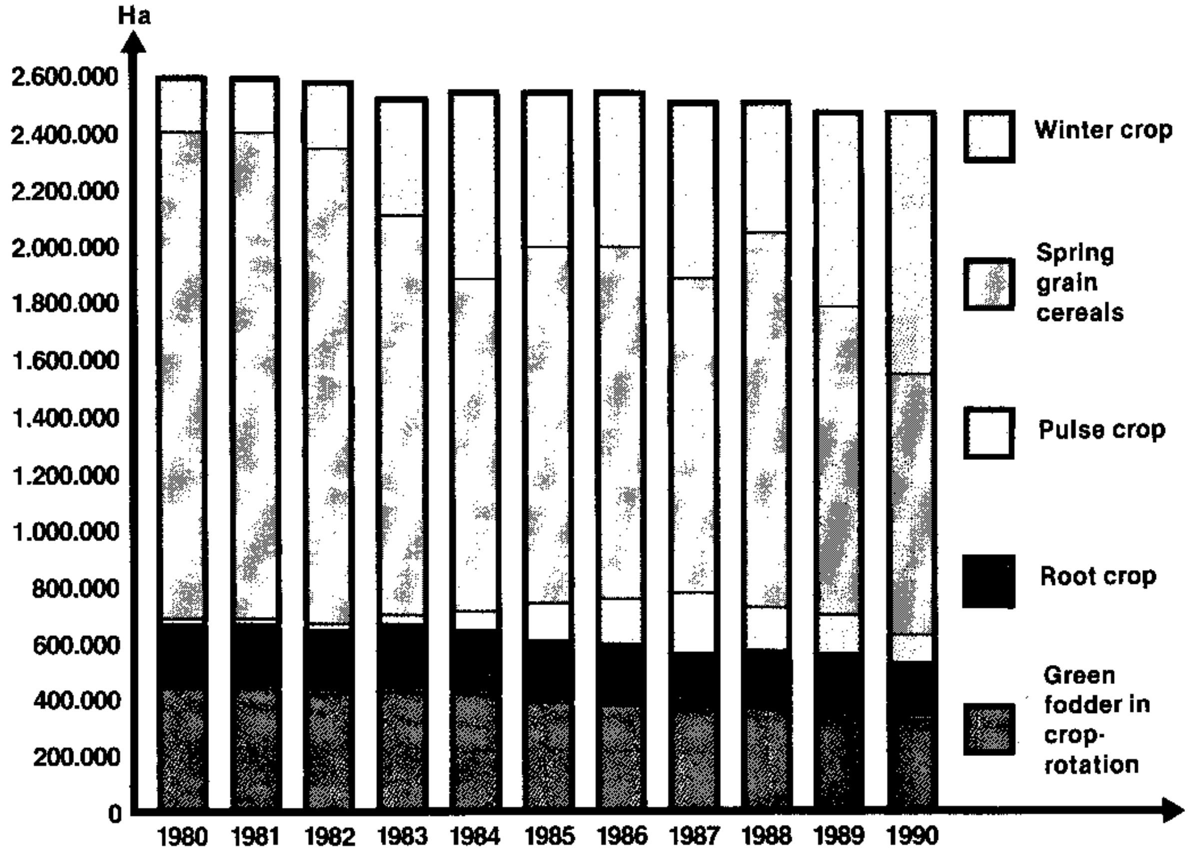

Figure 4.7

Developments in area use 1980-90 for the crops winter cereals (including winter rape), spring cereals (including spring rape), pulse, root crops and grass and green fodder in rotation (Danmarks Statistik 1980-90).

Changes in crops

The relative importance of the different crops has changed up through the 1980's. The most important trends being the increase in winter crop areas at the expense of especially the area with spring crops and the area with root crops in rotation. The changed crop structure has two reasons. The cattle population has fallen and there is therefore not the same requirement for coarse fodder by way of grass and beet. The requirement as to the extent of winter green fields can be fulfilled by growing winter cereals which has promoted especially this type of crop.

The result of the calculations in table 4.11 shows that a changed crop structure accounts for a reduction in nitrogen leaching of about 15,500 tons N in 1989/90 compared to 1980/82. It must be pointed out that the leaching reduction in 1987 especially was small on account of a wet autumn, which resulted in the establishment of a relatively modest winter cereal area (cf. the areas with winter cereals for harvesting in 1988 in figure 4.7). The effect of a changed crop structure may thus vary from one year to another depending on the climate.

	Change in N-leaching compared to 1980-82				
	1986	1987	1988	1989	1990
	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
Winter crop + -rape	+8.700	+4.200	+10.600	+17.000	+17.000
Spring grain cereals + -rape	÷20.100	÷14.600	÷23.700	÷34.400	÷32.300
Beet	÷2.900	÷4.500	÷4.800	÷5.400	÷5.700
Pulse crop	+9.800	+13.900	+9.900	+8.200	+6.600
Grass + greens in croprotation	÷900	÷1.300	÷1.200	÷1.300	÷1.300
Total Change	÷5.400	÷2.300	÷9.200	÷15.900	÷15.700

Table 4.11

The calculated reduction in leaching for the years 1986 to 1990 as a result of change in the crop structure. The crop changes have been calculated in relation to the average distribution of crops 1980-82 and multiplied with the average leaching figures for spring cereals, winter cereals, beet and grass, taken from figure 4.6. Leaching from pulse is estimated to 70 kg/ha, based on measuring (Blicher-Mathiesen 1990).

Ploughing in of straw

Ploughing in of straw is increasingly used in farming, i.e. as a result of the ban on burning of straw and the requirement of more green fields. When straw is ploughed in, nitrogen is fixed in the microorganisms, which decompose the straw, whereby nitrogen leaching is reduced.

The opinion research institute Observa has for the Danish Farmers Union (1989) performed an investigation showing that the area, in which straw was ploughed in, has increased by about 300,000 ha from the middle to the end of the 1980's. If it is assumed that ploughing in on average reduces the leaching by 10 kg N per ha, the total leaching reduction may be calculated to about 3,000 tons nitrogen per year.

In continuation of the above, it should be noted that Hansen et al. (1990) have carried out model runs with DAISY, which show that ploughing in of straw may reduce leaching the first couple of years, but that leaching will later increase if unchanged amounts of nitrogen are added. This indicates that the nitrogen requirements of crops in the long-term have to be adjusted with regard to the increased amount of nitrogen retained in the soil, if ploughing in of straw is not to result in increased leaching of nitrogen.

Decrease in agricultural area

The agricultural area has fallen by about 70,000 ha from 1985 to 1989, which decrease has either become natural areas, forests, roads or built up areas. Agricultural areas which are set aside by marginalization, cause less leaching – see leaching from areas with permanent grass in figure 4.6.

If the effect of setting aside one ha of arable soil is estimated to give as an average a reduction of nitrogen leaching of about 70 kg N per ha, the total effect may be calculated to be a reduction in nitrogen leaching of about 5,000 tons N.

In continuation of this, it can be concluded that marginalization or green fallowing must be considered as a particularly efficient way of reducing leaching of nitrogen from arable soil.

Extensification of agricultural areas

A general extensification, where e.g. the optimum fertilization consumption is reduced by 20%, also would lead to a reduction in leaching of nitrogen, se figure 4.4 – although not as big a reduction as by e.g. green fallowing. With regard to size, this reduction in leaching, where grain crops are concerned, may be estimated to about 5 kg N per ha for sand soils and somewhat less for clay soils.

4.1.11. Consumption of commercial fertilizers as a gauge of utilization of animal manure

The total requirement of nitrogen fertilizers in Denmark may be calculated approximately by multiplying the areas for each crop by the recommended fertilization standard, which appears from Handbook for Plant Cultivation (Agriculture's Information Office 1990). A precise calculation of the fertilization requirements in the individual year is, however, difficult since it is necessary to take into account type of soil residual effects of former fertilization, amount of nitrogen mineralized from the organic pool in the soil and how much of this nitrogen is leached during the winter.

The Danish requirement of fertilizers

Various calculations of the actual total Danish requirements of fertilizers show that it is between 400,000 (Hansen 1990c) and 450,000 tons of nitrogen (The Danish Farmers Union and Danish Family Farmers Association 1990) which means that in the following example the basis shall be a requirement of 425,000 tons per year. Besides, it should be pointed out here that requirements have been increasing in recent years on account of an increased area with winter cereals, which have a higher nitrogen requirement than spring cereals. Denmark's total fertilization requirement than spring cereals. The total fertilization requirement may thus be covered by 425,000 tons commercial fertilizer nitrogen, which however would be tantamount to the about 230,000 tons of nitrogen in animal manure, which is spread and left on the fields, not being utilized at all.

Utilization of animal manure

Recent experiments in the Agro-Economic Associations have shown that under optimal conditions it is possible to utilize up to 60-70% of total nitrogen in part of the animal manure. Moreover, it should be possible in average to utilize the nitrogen in manure by 40%, if it is spread in the spring in the right amounts (Pedersen & Østergaard 1990).

In figure 4.8 is illustrated the actual commercial fertilization requirements at different utilization percentages of nitrogen in animal manure. For comparison, the average consumption of commercial fertilizers from 1986-1989 is stated.

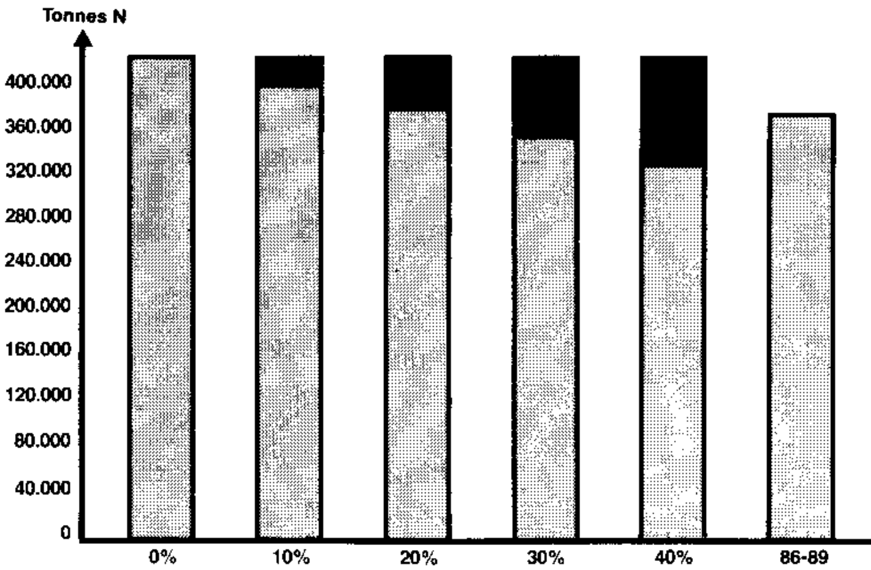

Figure 4.8

The commercial fertilization requirement at different utilization percentages of total nitrogen in animal manure. The bland part of the columns indicate animal manure nitrogen and the hatched area commercial fertilizer nitrogen. The average commercial fertilizer consumption from 1986-1989 is calculated on the basis of the agricultural statistics (Danmarks Statistik 1986-89).

From figure 4.8, it can be seen that the requirement of commercial fertilizers in case of a 40% utilization of animal manure can be calculated to about 330,000 tons of commercial fertilizer nitrogen. This corresponds to a saving of about 50,000 tons N compared to the present consumption – solely as a result of improved utilization of animal manure.

4.1.12. Survey of achieved reductions in the loss to the aquatic environment.

The effect valuations will here be concluded by a survey of the calculated reductions in nitrogen leaching as a result of changes in fertilization practices, crop structure, etc. from the middle of the 1980's until now.

	Tonnes N
Improved spreading of animal manure	4.000
Improved Manure planning	7.500
Change in cropstructure	15.500
Plowing down of straw	3.000
Decrease in agricultural land	5.000
Total N-leaching from fields	35.000
Waste water from the farm	15.000
The reduction in N-loss to the aquatic environment	50.000

Table 4.12 **Survey of the calculated leaching reductions and the reduction in the amount of »waste water from farms« as a result of changes in farming practices.**

In section 4.1.4, total leaching from the fields was stated to be about 210,000 tons N per year, as an average for the period 1987-1990. If it is assumed that a little more than half of the total reduction had taken effect in the middle of this period, it can thus be estimated that the leaching in the middle of the 1980's was in the order of 230,000 tons N per year.

The »waste water from farms« is, before the implementation of the Action Plan for the Aquatic Environment, estimated to have been about 20,000 tons N per year, which means that total nitrogen loss from agriculture in the middle of the 1980's may estimated to about 250,000 tons N per year.

It can thus be estimated that the achieved reduction in the nitrogen loss to the aquatic environment up to 1990 has been in the order of 20%. To this must be added an estimated reduction in ammonia volatilization of about 20,000 tons N per year as a result of more stringent requirements for plowing down or injection of animal manure.

4.2. Sewage Treatment Plants

Result of monitoring 1989

Based on the results of the monitoring programme, the discharge in 1989 and the expected discharge after the implementation of the Action Plan for the Aquatic Environment and the regional recipient quality plans, can be summarized as done in table 4.13.

Matter	Discharge 1989 according to the monitoring programme tonnes	Expected reduction tonnes	%	Discharge after the implementation of the programme tonnes
Organic matter	36.500	29.900	71	10.600
Nitrogen	18.000	11.400	63	6.600
Phosphorus	4.470	3.250	73	1.220

Table 4.13

Discharge from sewage treatment plants in 1989 and expected reduction in discharge after implementation of the Action Plan for the Aquatic Environment and the county recipient quality plans.

Background of the Action Plan for the Aquatic Environment

In the Plan, the NPO Report's figures were applied for the discharge from sewage treatment plants.

The discharge, the expected reduction and the discharge after the implementation of the Plan were calculated as it appears from table 4.14.

Matter	Discharge (1983/84) according to the NPO-statement tonnes	Expected reduction tonnes	%	Discharge after the implementation of the programme tonnes
Nitrogen	25.000	15.000	60	10.000
Phosphorus	7.200	5.200	72	2.000

Table 4.14

Discharge and expected reduction as calculated after the implementation of the Action Plan for the Aquatic Environment.

Differences in figures

When the figures are compared it looks as if during the period from 1983/84 to 1989 a decisively large reduction in the discharge has taken place.

Part of the difference in the figures is, however, due to the background and the prerequisites of the two surveys.

The earlier figures are primarily based on information on sizes of the sewage treatment plants, the purification levels, general conditions and permitted discharges, and only to a very limited degree on actual measurings. The result of the monitoring programme, however, is primarily based on a great number of measurings of the actual discharges from the sewage treatment plants.

It is, therefore, estimated that the results of the monitoring programme represents a satisfactory and more certain indication of the discharge level in 1989 than the earlier information for 83/84.

Based on the results of the monitoring programme it can be calculated that the earlier figures for the discharge from the sewage treatment plants are over-estimated, and that the discharge in the middle of the 1980's was around 20,000 tons nitrogen per year and around 6,000 tons phosphorus per year.

The difference between the 20,000 tons N and 6,000 tons P in 1983-84 and the 18,000 tons N and the 4,500 tons P in 1989 then expresses real reductions, partly as a result of improvement of some sewage treatment plants, partly as a result of an increased effectiveness and operation optimizing.

Something similar applies to the calculation of the discharge after the implementation of the Action Plan for the Aquatic Environment on the basis of the earlier calculations and on the new information obtained in connection with the monitoring programme, respectively. In addition, in the latest calculations, a reduction is included in the discharge as a result of new and revised recipient quality plans up to 1989.

It appears now, that the planned reduction will be reached. The discharges of nitrogen will be reduced by about 13,400 tons per year, or 67% and the discharges of phosphorus by about 4,800 tons per year, or 80%.

In using a considerable number of discharge measurings instead of theoretically fixed conditions to assess the discharge from the sewage treatment plants, it should be taken into account that variations year by year will not necessarily reflect a real development/improvement in the waste water treatment.

In such a calculation also extreme weather conditions (temperature and precipitation) and odd accidents and the like can affect the discharge in any individual year. How big such a variation will be, will appear from the monitoring in the years to come.

In tables 4.15, 4.16 and 4.17, discharges from sewage treatment plants are distributed on counties and on open water areas, as well direct discharge as discharges via watercourses and lakes. In the tables, in addition to N and P, the discharge of organic matter are given measured as COD and BOD5, respectively. Unlike the biochemical oxygen consumption over five days (BOD5), the chemical oxygen consumption (COD) also contains the oxygen consumption from sparingly degradable organic matter.

County	COD Tonnes	BI5 Tonnes	Total-N Tonnes	Total-P Tonnes
Copenhagen	22.900	6.740	4.580	1.180
Frederiksborg	3.490	1.140	982	287
Roskilde	1.840	554	882	205
West Zealand	2.890	1.060	890	247
Storstrøms	6.500	2.620	1.030	343
Bornholms	4.090	1.970	343	80
Funen	9.030	3.730	1.150	343
South Jutland	5.310	1.900	824	223
Ribe	5.550	2.760	1.200	176
Vejle	11.600	4.600	1.360	345
Ringkøbing	2.320	497	531	73
Århus	10.700	4.130	1.860	458
Viborg	5.270	1.680	739	156
North Jutland	6.780	3.060	1.640	344
Total	98.200	36.500	18.000	4.470

Table 4.15 **Discharge from sewage treatment plants in 1989 distributed by counties.**

Note: Three local sewage treatment plants have not been included in tables 4.15, 4.16 and 4.17. The discharges from the sewage treatment plants at Hanstholm, Skagen and Hirtshals consist mainly of waste water from the fishing industry, and these discharges have therefore been included in section 4.4.

Waters	COD Direct Tonnes	COD By streams and lakes Tonnes	BI5 Direct Tonnes	BI5 By streams and lakes Tonnes
1. The North Sea	4.890	4.140	2.580	862
2. Skagerrak	226	712	100	171
3. Kattegat	8.490	9.880	3.510	3.270
4. The North Belt	6.400	5.340	2.850	1.680
5. The Little Belt	13.200	2.150	5.760	575
6. The Great Belt	8.460	3.180	3.920	682
7. The Sound	24.400	907	7.220	308
8. The South Belt	215	128	595	49
9. The Baltic Sea	4.350	1.110	2.090	213
Total	70.700	27.600	28.600	7.800

Table 4.16

Discharge of organic matter from sewage treatment plants in 1989 distributed by open water areas - direct and via watercourses and lakes.

Waters	Total-N Direct Tonnes	Total-N By streams and lakes Tonnes	Total-P Direct Tonnes	Total-P By streams and lakes Tonnes
1. The North Sea	941	1.000	94	234
2. Skagerrak	30	149	4	58
3. Kattegat	1.820	2.270	393	580
4. The North Belt	574	1.360	180	316
5. The Little Belt	1.240	578	354	166
6. The Great Belt	962	892	249	261
7. The Sound	5.200	347	1.330	101
8. The South Belt	148	23	39	8
9. The Baltic Sea	371	97	89	44
Total	11.300	6.700	2.700	1.770

Table 4.17

Discharge of nitrogen and phosphorus from sewage treatment plants in 1989 distributed by open water areas - direct and via watercourses and lakes.

Waste water outside sewage catchment areas

Discharge of waste water outside sewage catchment areas consists of discharge from sparsely built-up areas and from villages and summer house areas without sewage systems.

The volume of the discharge has been estimated as it appears from table 4.18.

The calculation is subject to very great uncertainty, and it does not appear to which recipient areas and types the discharges are led.

When the Action Plan for the Aquatic Environment is implemented, the discharge from areas outside sewage catchment areas will constitute a not insignificant part of the total discharges to the aquatic environment.

The National Agency of Environmental Protection, therefore, will in the years to come try to improve the calculations by help of the monitoring programme.

Discharge	N per year	P per year	BI5 per year
Outlet from villages to			
the soil	400	120	1.300
surfacewater	400	120	1.300
Outlet from the farmhouse to			
the soil	550	230	2.700
surfacewater	880	250	2.200
Outlet from the area of summercottages* to			
the soil	330	100	1.200
surfacewater	330	100	1.200
Total outlet out of			
the seweraged areas	2.890	920	10.400
the soil	1.280	450	5.200
surfacewater	1.610	470	5.200

* Outlet takes place 3 months per year.

Table 4.18 **Estimate of the discharge of domestic waste water outside sewage areas.**

4.3. **Outlets conditioned by rainwater**

Volume of discharges

Discharges from overflow structures and separate discharges in a normal year, distributed on counties, appears from tables 4.19 and 4.20.

In tables 4.21 and 4.22, the discharges are distributed on open water areas - direct as well as via watercourses and lakes.

The total discharge is 13,400 tons COD, 810 tons N and 199 tons P.

At the beginning of the 1980's, discharges from outlets conditioned by rainwater was made up to be 1,750 tons BOD5, 745 tons N and 95 tons P.

The difference between the two estimates is thought to be due solely to uncertainty of the assumptions applied.

County	Water 10^6 m^3	COD Tonnes	Total-N Tonnes	Total-P Tonnes
Copenhagen municipality	4,6	630	53	14,8
Copenhagen	2,2	320	27	6,7
Frederiksborg	2,6	320	27	7,0
Roskilde	0,8	120	10	2,8
West Zealand	3,1	380	31	8,9
Storstrøm	2,3	330	28	7,3
Bornholm	0,5	63	5	1,4
Funen	4,0	550	46	12,4
South Jutland	2,6	330	27	6,8
Ribe	3,1	460	38	10,0
Vejle	2,0	300	25	6,6
Ringkøbing	3,2	460	38	9,8
Århus	6,9	950	79	17,5
Viborg	2,3	300	25	6,5
North Jutland	5,1	710	59	15,1
Total	45	6.200	519	134

Table 4.19 **Discharge from overflow structures in a normal year distributed by counties.**

County	Water 10^6 m^3	COD Tonnes	Total-N Tonnes	Total-P Tonnes
Copenhagen municipality	1,2	62	2,5	0,6
Copenhagen	18,0	910	36,2	8,9
Frederiksborg	4,9	250	10,0	2,4
Roskilde	4,5	220	8,8	2,2
West Zealand	8,5	320	12,9	3,1
Storstrøm	5,3	270	10,7	2,7
Bornholm	1,0	51	2,1	0,5
Funen	9,0	450	18,1	5,2
South Jutland	9,1	690	27,7	6,6
Ribe	4,1	210	8,2	2,0
Vejle	7,0	350	14,0	3,5
Ringkøbing	14,2	630	25,1	6,3
Århus	22,8	1.900	74,8	12,1
Viborg	5,6	250	9,8	2,4
North Jutland	13,7	690	27,4	6,7
Total	129	7.200	290	65

Table 4.20

Discharge from separate discharges in a normal year distributed by counties.

Note: Figures for Bornholm County are estimated by the National Agency of Environmental Protection.

Waters	COD Tonnes	Total-N Tonnes	Total-P Tonnes
1. The North Sea	180	12,7	3,3
2. Skagerrak	60	3,7	0,9
3. Kattegat	1.200	73,7	17,8
4. The North Belt	570	32,2	6,6
5. The Little Belt	300	18,1	4,4
6. The Great Belt	390	23,9	7,0
7. The Sound	1.300	69,8	17,6
8. The South Belt	26	1,5	0,4
9. The Baltic Sea	69	4,5	1,2
Total	4.100	240	59

Table 4.21

Direct discharges in a normal year distributed by open water areas.

Waters	COD Tonnes	Total-N Tonnes	Total-P Tonnes
1. The North Sea	1.900	112,4	28,8
2. Skagerrak	140	8,7	2,2
3. Kattegat	2.800	169,6	40,5
4. The North Belt	1.500	83,1	17,5
5. The Little Belt	950	52,8	13,6
6. The Great Belt	920	60,3	15,7
7. The Sound	960	69,3	18,8
8. The South Belt	45	2,9	0,8
9. The Baltic Sea	130	8,0	2,1
Total	9.300	570	140

Table 4.22 **Discharge from outlets conditioned by rainwater via watercourses and lakes, in a normal year, distributed by open water areas.**

Note: The distribution of the discharge between direct and via watercourses and lakes is estimated by the National Agency of Environmental Protection for the counties Funen, Aarhus and North Jutland.

Share of discharge

The discharge from outlets conditioned by rainwater constitute only a small percentage of the total discharge from sewages (sewage treatment plants and outlets conditioned by rainwater).

The percentage for organic matter, expressed by COD, is 12%, and for nitrogen and phosphorus, 4.3%.

If only fresh waters are considered, the percentage is, however, about 25% for organic matter, 8% for nitrogen and 7% for phosphorus, which illustrates that waste water in the treatment plants is subjected to better treatment than average when the discharge is to fresh waters, or that the waste water discharge itself has been moved to a marine recipient.

The discharge from outlets conditioned by rainwater will constitute a larger share of the total load when the large treatment plants have been improved in accordance with the Action Plan for the Aquatic Environment.

Today, there are only few regional recipient quality plans dealing with outlets conditioned by rainwater. As the larger treatment plants are improved, and the planning foundation in the counties improved, it must be expected that the outlets conditioned by rainwater will be regulated to a much greater extent than now.

4.4. Separate discharges from industry

This section deals with the separate discharge of industrial waste water containing nitrogen, phosphorus and organic matter to marine and freshwater areas. Moreover, a summing up is made of the amounts of nitrogen, phosphorus and organic matter which are sprayed out with industrial waste water on agricultural areas.

Basis of the survey

This survey is based especially on reporting of the counties in connection with the countrywide monitoring programme.

Delimitations of the survey

In the survey known data of all separate industrial discharges have as a rule been included.

The following discharges are been included in the survey:

- all cooling water discharges,
- all discharges less than a negligible limit fixed at 30 PE,
- all sorts of fish farms, as a separate summary of these is made elsewhere in this report,
- discharges from the defrosting of road bridges and airfields, as the load of water areas is unknown in most such cases.

In addition to the separate industrial discharges, three discharges from municipal treatment plants are included, as they contain industrial waste water to an extent which is estimated to be around 90-95% of the total amount.

Where no measuring results are available, the discharged amounts are estimated to the widest extent possible.

Extent of the survey

In the survey below, a total of 170 point sources are included, distributed on 67 discharges to marine areas, 39 discharges to fresh waters and 64 sprayed or percolated sources.

The data basis for the 1984 values is I. Krüger's reports: »Direct discharge of industrial waste water« (1984) and »Spraying of industrial waste water« (1984). These comprise 58 discharges to marine areas, 20 discharges to fresh waters and 96 sprayed or percolated sources.

Discharged amounts of substances

Table 4.23 shows the discharged amounts of nitrogen, phosphorus, BOD5 and COD to the water areas in 1989 compared with the calculations for 1984.

	Nitrogen		Phosphorus		BI5		COD	
	1984	1989	1848	1989	1984	1989	1984	1989
County	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
Copenhagen (local council)	0	0	0	0	0	0	0	0
Frederiksberg (local county)	0	0	0	0	0	0	0	0
Copenhagen county	0	0	0	0	0	0	0	0
Frederiksborg county	100	5	0	1	26	17	54	0
Roskilde county	147	199	25	11	6.530	6.801	28.123	24.120
West Zealand county	272	486	68	54	1.621	4.175	4.058	7.377
Storstrøm county	211	228	16	16	6.184	4.361	10.934	6.897
Bornholm county	0	4	0	0	0	0	0	0
Funen county	82	155	16	5	2.560	1.568	5.407	3.075
South Jutland county	56	99	13	13	275	260	1.200	13
Ribe county	572	683	54	14	5.053	1.869	10.308	2.444
Vejle county	1.249	959	1.877	132	7.622	7.371	30.325	3.412
Ringkøbing county	746	363	1.040	715	4.220	3.634	8.379	8.866
Århus county	355	89	27	7	2.815	1.075	6.817	2.758
Viborg county	89	219	9	22	635	1.162	1.241	1.590
North Jutland county	405	585	44	36	3.753	3.713	7.134	53
Discharge from municipality 1)	-	250	-	50	-	2.000	-	3.000
Discharge from municipality 2)	-	655	-	119	-	5.717	-	9.794
Total, excl. 1) + 2)	4.284	4.074	3.189	1.026	41.294	36.006	113.980	60.605
Total, incl. 1) + 2)	-	4.979	-	1.195	-	43.723	-	73.399

Table 4.23 **Discharge of nitrogen, phosphorus, BOD5 and COD in 1984 and 1989 to fresh and marine areas from industries with separate discharges.**

1) local discharges in Viborg county

2) local discharges in the North Jutland county.

A direct comparison of these two calculations is difficult to make for several reasons:

- Since 1984 more industries have become connected to the local waste water treatment plants, whereas a few, conversely, have had separate discharges established.
- The data basis for the 1984 – and 1989 – calculations is of varying quality. The basis for the 1989 calculation must be considered to be more detailed, both with regard to number and content of the individual discharges.

Development in the discharges

If the three discharges from municipal waste water treatment plants, which were not included in the 1984 calculation, are disregarded, it is seen that the discharged amounts of nitrogen and BOD5 have fallen slightly, whereas there has been a considerable reduction in the discharges of phosphorus and COD.

Thus, the requirements to reductions of the discharges of nitrogen and phosphorus which, according to the Action Plan for the Aquatic Environment, have been set up with respect to 19 separate dischargers, have until 1989 resulted in only a small reduction of the nitrogen discharges.

The reduction in the discharged amounts of phosphorus is due especially to the reductions in discharges from the two chemical firms, Kemira and Cheminova.

Sprayed amounts of substances

Table 4.24 shows the sprayed amounts of nitrogen, phosphorus, BOD5 and COD on agricultural soil in 1989 compared with the calculalations for 1984. In the survey one percolation plant has been included.

	Nitrogen		Phosphorus		BI5		COD	
	1984	1989	1848	1989	1984	1989	1984	1989
County	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
Copenhagen (local council)	0	0	0	0	0	0	–	0
Frederiksberg (local county)	0	0	0	0	0	0	–	0
Copenhagen county	0	0	0	0	0	0	–	0
Frederiksborg county	0	0	0	0	0	0	–	1
Roskilde county	0	0	0	0	0	0	–	0
West Zealand county	6	2	2	0	35	20	–	22
Storstrøm county	1	0	0	0	22	0	–	0
Bornholm county	6	1	1	0	30	0	–	0
Funen county	13	24	2	2	390	410	–	584
South Jutland county	106	217	36	33	1.500	2.265	–	2.622
Ribe county	31	74	12	20	235	15	–	0
Vejle county	24	13	7	5	130	215	–	220
Ringkøbing county	247	355	45	50	1.300	3.072	–	356
Århus county	135	141	33	22	1.400	138	–	0
Viborg county	127	456	46	39	1.750	3.204	–	242
North Jutland county	203	233	61	46	2.090	3.094	–	4.764
Total	899	1.516	245	217	8.882	12.433	–	8.811

Table 4.24 **Sprayed amounts etc. from industry, of nitrogen, phosphorus, BOD5 and COD, in 1984 and 1989.**

It can be seen that the amounts of nitrogen and BOD5 have increased since 1984. At the same time the number of enterprises spraying waste water has fallen.

Enterprises spraying out substances

Depending on the measuring parameter, 70-85% of the volumes sprayed out comes from potato flour plants, and 7-20% from dairies. The rest originates mainly from different forms of treatment of fruit and vegetables.

Five potato flour plants spray out waste water containing more than 66 tons nitrogen per year and 7.5 tons phosphorus per year, and one dairy sprays waste water containing more than 7.5 tons phosphorus per year. Therefore, they are comprised by the requirement to reduce the amounts by means of the best available technology.

Spraying on agricultural soils according to the rules now in force is considered to be the best available technology for reducing nitrogen and phosphorus loads. Leaching of nitrogen to the water areas from the five potato flour plants is expected to be reduced by 75% from 1989 to 1993.

Distribution on open water areas

In table 4.25, the discharged amounts are distributed on the main open water areas. It can be seen that by far the largest amounts of nitrogen, phosphorus and organic substances are discharged to marine areas, but these discharges are small compared with discharges from other sources.

	Nitrogen		Phosphorus		BI5		COD	
	Marine	Fresh	Marine	Fresh	Marine	Fresh	Marine	Fresh
Marine waters	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
1 The North Sea	916	135	720	10	5.458	45	10.861	449
2 Skagerrak	765	0	131	0	5.988	0	9.044	0
3 Kattegat	1.022	18	102	3	7.581	58	8.003	129
4 The North Belt	91	3	0	0	38	46	0	75
5 The Little Belt	1.106	10	148	1	9.155	18	6.494	5
6 The Great Belt	622	62	63	4	8.338	11	13.721	40
7 The Sound	198	1	11	0	6.800	1	24.141	3
8 The South Belt	0	7	1	0	0	13	0	68
9 The Baltic Sea	22	0	1	0	172	0	365	0
Total	4.742	236	1.177	18	43.530	192	72.629	769

Table 4.25

Discharges of nitrogen, phosphorus, BOD5 and COD to the main water areas in 1989.

The relatively large discharges of nitrogen to the North Sea, the Skagerrak and the Kattegat are mainly due to different forms of fishing industry, while, as far as the discharges of nitrogen to the Little Belt and the Great Belt are concerned, it is the artificial fertilizing industry (Kemira), which is accountable for about 66%, and the drug industry (Novo-Nordisk), which is accountable for about 50%, respectively.

97% of phosphorus discharges to the North Sea stem from production of pesticides (Cheminova).

The great loads of BOD5 and COD to the North Sea, the Skagerrak and the Kattegat are mainly due to the fishing industry and production of pesticides, while in the Little Belt, the Great Belt and the Baltic Sea it is the sugar plants, cellulose factories and the drug industry which are accountable for the major part of the discharges.

Seasonal variations

With respect to the Little Belt, and particularly the Great Belt, it should be noted that there are large seasonal variations in the marine discharges on account of the campaign period of the sugar plants. Thus, discharges for all four discharge parameters may be double the size in October, November, December and January compared with the other months of the year.

Distribution on industrial sectors

In table 4.26 the total discharged and sprayed out amounts are distributed on industrial sectors.

Number, type of concern	Nitrogen Tonnes	Phos-phorus Tonnes	BI5 Tonnes	COD Tonnes
3 Refineries	141	1	93	942
9 Chemical enterprises	212	7	287	943
9 Feeding stuff and granaries	94	20	79	3
5 Slaughter houses	97	13	355	1
34 Dairies	101	44	1.146	1.237
4 Storage and dumping grounds	95	0	1	2
1 Fertilizer industries	690	94	23	0
3 Medical factories	348	45	2.697	5.756
1 Chemical industries	93	699	2.611	8.101
6 Cellulose and paper	298	48	14.199	27.457
7 Potato flour factories	1.281	149	10.457	6.690
6 Sugar mills	278	23	7.393	11.704
15 Fish products	1.627	79	7.769	4.416
3 Treatment plants (fish industries)	906	169	7.717	12.794
58 Others	234	22	1.328	2.163
The Total of 164	6.495	1.413	56.155	82.209

Table 4.26 **Total marine and freshwater discharges and sprayed amounts of nitrogen, phosphorus, BOD5 and COD in 1989 distributed on industrial sectors, including three local discharges.**

The 19 dischargers which, as a result of the Action Plan for the Aquatic Environment, are to reduce the discharges of nitrogen and phosphorus by means of the best available technology are within the sectors: Chemical enterprises (3), slaughterhouse (1), the artificial fertilizer industry (1), drug companies (2), pesticides factory (1), cellulose plants (2), sugar plant (1), fish products (5) and others (3).

Expected results

As a result of the measures initiated until 1993 a reduction of 1900 tons nitrogen per year is expected, and until 1995 a further reduction of 600 – 700 tons nitrogen per year is expected as a result of the termination of treatment plants at the fish and herring oil factories. In addition to the already obtained reduction of 2,000 tons phosphorus, until 1993 a further reduction of 900 tons phosphorus per year is expected, as result of further reductions in waste water discharges from Kemira and Cheminova. Also, a considerable reduction of BOD5 and COD is expected; the size of this reduction cannot at present be estimated.

This means that the objectives of the Action Plan for the Aquatic Environment concerning the reduction of the nitrogen discharges are reached, and that the reduction in phosphorus discharges will be larger than the objectives of the Plan.

4.5. **Aquaculture**

Fish farms

In 1989, the total load of watercourses with nutrients from fish farms was 2,192 tons nitrogen and 238 tons phosphorus, (see table 4.27).

In April 1989, a Statutory Order was issued concerning freshwater fish farms. The object of the Order is to limit the pollution from fish farms – first of all the pollution of watercourses, but also the resulting discharge of nutrients to lakes and the sea. The watercourse pollution, as it is expressed in increasing saprobe value (pollution degree), is not so much due to the nutrients as to organic matter (BOD5). In 1989, in 60% of the fish farms an unacceptable state of pollution was found, with higher degree of pollution downstream the fish farm than upstream.

Marine waters	BI5 Tonnes	Total-N Tonnes	Total-P Tonnes
1. The North Sea	4.489	1.536	163
2. Skagerrak	64	13	2
3. Kattegat	1.256	475	54
4. The North Belt	25	10	1
5. The Little Belt	412	158	18
6. The Great Belt	0	0	0
7. The Sound	0	0	0
8. The South Belt	0	0	0
9. The Baltic Sea	0	0	0
Total	6.246	2.192	238

Table 4.27

Discharge of BOD5, total-N and total-P from fish farms to fresh waters in 1989 distributed on main water areas.

The immediate results of the Order will be a certain reduction of the production in fish farms. The goal is not a general reduction in all fish farms. The demand to reduce pollution will, of course, hit the most polluting fish farms the hardest. The production level is laid down for the individual farm by fixing limits for the highest annual fodder consumption. This will enable the users to increase production later by improving fodder and feeding techniques.

It is expected that the Order will, within some years, fulfil its objective, i.e. contribute to the fulfilment of the quality objectives of the watercourses and to reduce the load of nutrients in lakes and the sea.

Marine aquaculture and marine-water fish farms

Pollution from marine aquaculture farms constitute only a smaller part of the total load of the sea. It is a local phenomenon which is strongly dependent on the water currents near the individual farm.

Only few salt-water farms are in operation so far. Their total production constitute only a few percentage of the marine aquaculture farm-production. Besides, as they treat the waste water, their pollution share is so small that it may be disregarded here.

On October 1, 1990, a new Statutary Order, issued by the Ministry of the Environment, came into force concerning salt-water based fish farming. It lays down rules for operation of the farms and, as the Order on fish farms, it animates to use better and less polluting fodder and the best possible feeding techniques. This development has already started. The fodder quotient (kg fodder per kg produced fish) has thus fallen from 1.7 to 1.4 during the period 1986-1989. This improvement of the feeding technique has contributed to an increase in production during the same period by 68%, while the calculated discharges of nitrogen and phosphorus only increased by 28% and 8%, respectively, to a total of 322 tons and 44 tons.

4.6. **Energy and Traffic**

Power plants

The annual emissions from the power plants of oxidized nitrogen, NO_x, shall, according to the Act on control of discharge of sulphur dioxide and nitrogen dioxide from power plants, be reduced from 40,800 tons nitrogen in 1985 to 22,800 tons in year 2000 and further down to 18,300 tons nitrogen by the year 2005.

Automobiles

US standards for passenger cars and small vans were introduced in Denmark as from October 1, 1990. Both inside the EEC, and in a number of countries outside the EEC, work is presently going on to lay down stringent standards for other categories of vehicles – larger vans, trucks and busses. It is expected that such standards will come into force during the first of half of the 1990s.

In the calculations, which were carried out in 1988, on the assumption of the introduction of more stringent standards, it was, with regard to all categories of vehicles, estimated that a decrease would be obtained in the NO_x-discharge from about 23,400 tons nitrogen in 1985 to around 18,300 tons nitrogen by the year 2000. However, already now there are essential deviations from the assumptions then used for the evaluation of the development in transportion. The estimate made for the situation in year 2000, cannot, therefore, be expected to be reached. However, there are no new calculations at this present time.

Other sources

The discharge of NO_x from other sources (district heating plants, industry and individual heating) is expected to be reduced modestly during the period 1985-2000.

Through the implemented initiatives, with the above reservations concerning transport, it is expected that the total NO_x-emission by year 2000 will be 53,000 tons nitrogen corresponding to a reduction of just over 30%.

4.7. Input of nitrogen from the atmosphere

Detailed surveys of deposition of nitrogen from the atmosphere have been made under the European Monitoring and Evaluation Programme, see section 2.7.3.

The latest EMEP-calculations for nitrogen dioxide (NO_x) and ammonium/ammonia (NH_x) were made for the year 1988, (Iversen 1990). The emission figures for 1988 for Denmark used in the calculations are 106,000 tons reduced nitrogen (NH_x-N) from agriculture and 76,000 tons oxidized nitrogen (NOx-N) from industry, power works and transportation.

The deposition calculations for 1988 for nitrogen are divided on oxidized nitrogen (NO_x-N) and reduced nitrogen (NH_x-N), respectively. The origin of nitrogen deposited, dry as well as wet, on the Danish land areas, about 43,000 km, may according to the reference (Iversen 1990) be calculated as follows:

	NO_x-N	NH_x-N
West Germany	7.100	3.000
Denmark	1.700	44.700
Great Britain	6.300	1.700
The Netherlands	2.000	1.700
GDR	1.800	1.500
Sweden	500	500
France	1.700	900
Czechoslovakia	600	200
Poland	1.400	1.100
Other countries	2.700	1.300
Not determined	2.200	1.800
Total input to Denmark	28.300	58.500

Table 4.28 **Origin of NO_x-N and NH_x-N deposited on the Danish land area in 1988 stated in tons nitrogen.**

The calculations show that Denmark is a considerable net exporter of both oxidized nitrogen and ammonia-nitrogen.

The table, moreover, gives a total nitrogen deposition of 86,800 tons on Danish land areas.

It is established that the main part of the NH_x-deposition originates from Danish sources, whereas the NO_x-deposition mainly stem from foreign sources, especially Germany and England.

Denmark net export is about 47,600 tons NH_4-N and 48,000 tons NO_3-N. If the nitrogen deposition over Danish territorial waters is taken into account, that the net export is considerably lower.

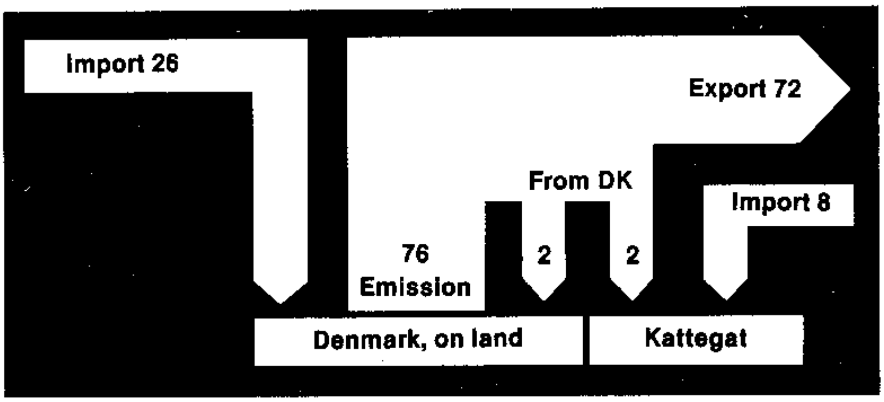

Figure 4.9

Import/export balance for NO_x for Denmark. In thousand tons NO_x-N per year. Deposition on land areas is according to Iversen (1990) **and deposition on the Kattegat is according to Asman** (personal communication).

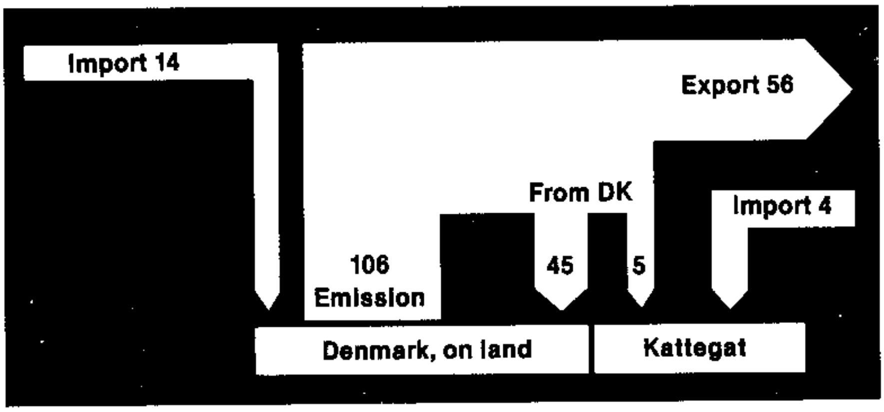

Figure 4.10

Import/export balance for NH_x for Denmark. In thousand tons NO_x-N per year. Deposition on land areas is according to Iversen (1990) **and deposition on the Kattegat is according to Asman** (1990b).

According to calculations made by Asman (personal communication) the NO_x-deposition on the Kattegat is just about 10,000 tons N per year. Similarly the NH_x-deposition is calculated to a little less than 10,000 tons N per year (Asman 1990b). About 53% of the NH_x-deposition originates from Danish sources, whereas only about 20% of the NO_x-deposition comes from Denmark. The most important foreign sources of nitrogen deposition on the Kattegat are Germany and England.

5. Status and trends in the state of the aquatic environment

The discharges described in Chapter 4 have resulted in the present state of the aquatic environment.

In Chapter 5 the state and trends of the aquatic environment will be presented.

With regard to ground water it is illustrated how the changes in the ground water quality are distributed regionally, and how the nitrogen leaching from fields affects the Danish ground water resources.

For streams and lakes it is described how the present state corresponds to the objectives. Also, the possibilities of obtaining improvements in the present conditions are illustrated.

Finally, the development of the conditions of the near-shore waters and the open seas is discussed. The importance of the Danish contributions of nutrients compared with the contributions from elsewhere are especially evaluated.

5.1. Ground water

Ground water monitoring areas

In connection with the nationwide monitoring programme, 68 ground water monitoring areas have been established with more than 1,000 testing stations. (National Agency of Environmental Protection 1989). The establishment of ground water monitoring areas is now completed, and sampling and analyzing methods have been developed. The first measuring results are arriving, but are not yet on an accessible form.

In connection with the reporting of the monitoring programme in the year to come, the results of the ground water monitoring areas will constitute an important reference basis for the description of the ground water quality being prepared based on the drinking water and untreated ground waster data base of the National Agency of Environmental Protection and Geological Survey of Denmark. Actual time series will, as a matter of course, not be available until after a number of years.

Data basis for reporting

The present reporting on the ground water content of nitrate and phosphorus is primarily based on information from the drinking water and untreated ground water data base.

This data base contains information on the drinking water quality in nearly all water works in Denmark with an annual pumping rate of more than 10,000 m. They represent well over 600 million m, corresponding to more than 90% of the drinking water supplied by the water works of the country.

However, it should be emphasized that when drinking water data are used to describe the ground water quality, a number of reservations must be made in connection with the interpretation of development trends.

Primarily, it should be noted that information on the status and development in the drinking water quality will, to a considerable extent, reflect the initiatives which are continuously being taken with regard to supply techniques, which are currently implemented in order to change abstraction from high-load to low-load areas or ground water reservoirs. For example, this is done by way of new sources, new borings, mixing of water from several borings or discontinuance of water works with the highest content of pollutants.

Such initiatives will generally result in an improved drinking water quality, but do not, of course, have any effect on the ground water quality.

5.1.1. **Status and development of ground water quality**

Selection of drinking water data to evaluate ground water quality

An evaluation of the ground water quality presupposes an elimination of the effects of the mentioned restructuring of supply techniques. In order to obtain the most realistic picture of the ground water quality, some 1,400 water works, which each only abstract from one ground reservoir, have been selected. (Gosk et al. 1990).

In spite of this selection, estimates of the ground water quality, on the basis of information from the drinking water data base, will still be optimistic, as effects of other changes in supply techniques cannot be completely disregarded. To this comes an influence on ground water reservoirs which may be a result of the water abstraction (cf. section 3.1.1).

5.1.2. **Nitrogen in ground water**

Based on the reduced data base, two maps have been drawn indicating the general nitrate content of ground water and the development in the nitrate load (figures 5.1 and 5.2). The nitrogen content in water from the selected works is considered representative for the content in the ground water.

Two water works in the same local area may have different nitrate values and development trends, as they do not necessarily abstract from the same ground water reservoir. The maps illustrate, therefore, the general nitrate conditions in the ground water reservoirs, from which drinking water is abstracted, and do not differentiate between whether the abstraction is made from upper or deeper reservoirs.

Status of ground water quality

Figure 5.1 shows the status of the nitrate level. On the islands the content is generally low, usually under 5 mg per litre, but certain areas are seen with increased, or very high content of nitrate (from 25 to more than 50 mg per litre). For example at Stevns, South Zealand, Møn, Falster, in the area around the inlet Roskilde Fjord, the north-west and southern Funen and in the island Samsø.

Throughout Jutland, areas are found with increased or very high nitrate values (from 25 up to more than 50 mg per litre), but especially the northern part of Jutland must be characterized as generally strongly nitrate loaded. The nitrate level in the area from Limfjorden down to and including Djursland must be characterized as directly critical for the water supply.

Developments in ground water quality

Figure 5.2 shows developments in the nitrate level. The general pisture is a considerable overweight of areas where an increasing nitrate content in the ground water reservoirs are found.

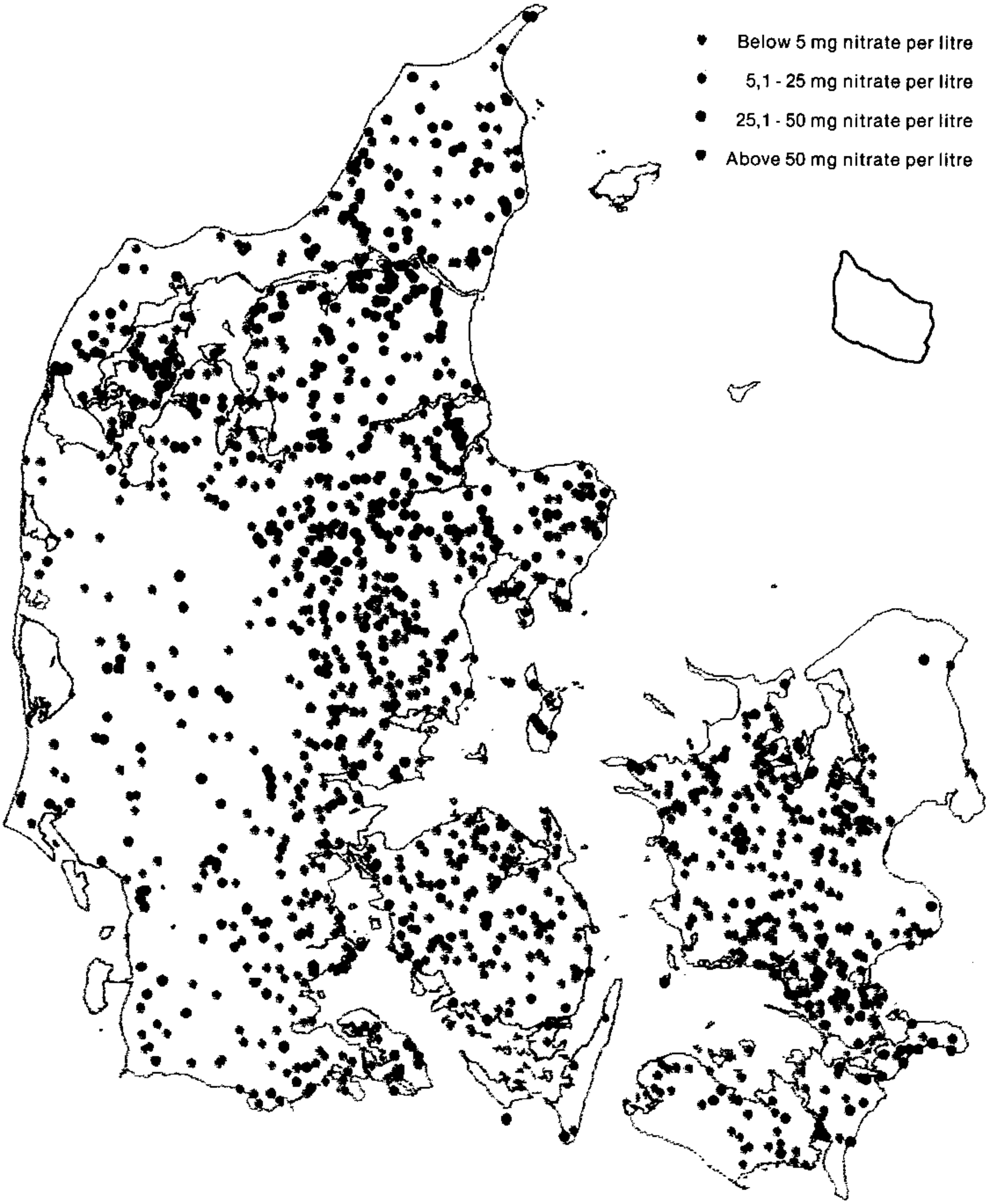

Figure 5.1 **The nitrate content in the ground water from selected water works in Denmark.**

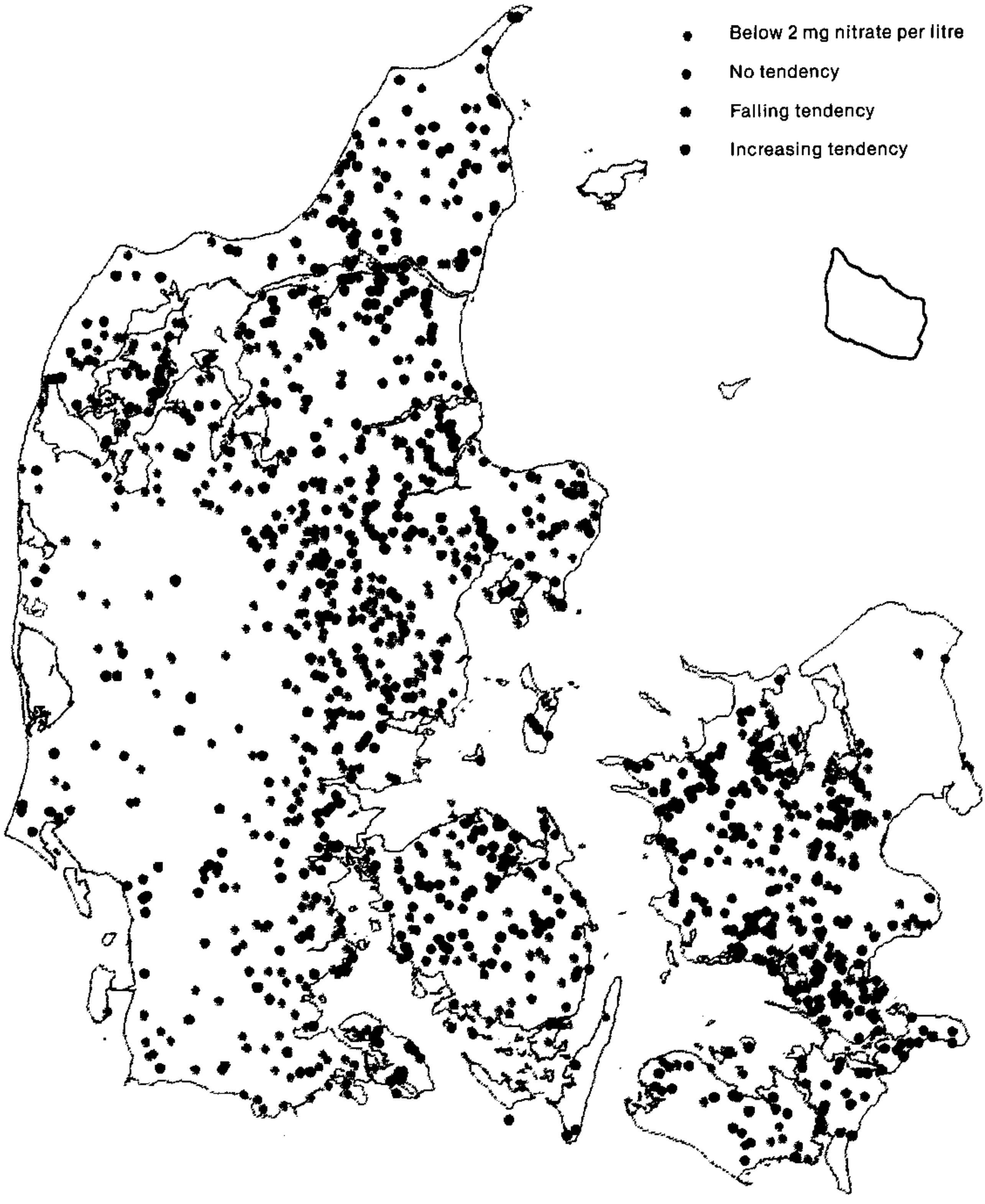

Figure 5.2 **Development trends in the nitrate content in ground water from selected water works in Denmark.**

In the islands, scattered areas with increasing nitrate content can be found, especially in South Zealand, Lolland-Falster and north-west Funen.

Throughout Jutland, there are areas with increasing nitrate content, but the most significant development trends are found in the western and northern part.

Nitrate load and natural protection

The described levels and development trends are closly linked to the nitrate load from agriculture and the geological structure of the areas.

The large areas of North Jutland, where an increasing nitrate level are found – and where the actual level must be described as critical – are typically characterized by a poor natural protection of the ground water. To this comes, that the possibilities of abstracting drinking water from the deeper reservoirs are very limited.

In the western part of Jutland, the upper ground water reservoirs is similarly poorly protected, or an insufficient nitrate reduction takes place in the existing strata of clay, in relation to the actual load. Here, however, possibilities of abstracting drinking water from deeper reservoirs exists.

In the islands the natural protection of the ground water is generally good and the nitrate load less. The fact, that it is possible to point out areas in which the nitrate content is developing critically must be ascribed to local variations in the geological picture or that the nitrate reducing effect in the protecting strata of clay is no longer sufficient. The development in Lolland-Falster is probably due to an increased ammonium load.

5.1.3. **Phosphorus in the ground water**

In some parts of the country an increased content of phosphorus in the drinking water are found. This applies particularly to Vendsyssel and, to some extent, to the western and southern parts of Jutland. The reasons are probably, as mentioned earlier, that some of the drinking water is abstracted from reservoirs in marine sediments with a naturally high content of phosphorus.

Any increased content of phosphorus in ground water will most often be precipitated with iron by traditional water treatment and is, therefore, rarely a quality problem in the water supply.

5.1.4. **Size of the ground water resource**

Calculation of the volume of the ground water resource

It is difficult to make a precise calculation of the volume of the ground water resource on a national basis, as there is no uniform method to make such a calculation.

The present calculation, therefore, is made on the basis of a simplified method developed in connection with a project under the Water Council (1990).

These evaluations give, on a regional level, a conservative, but realistic estimate. Future more certain resource calculations presuppose new and more complicated methods.

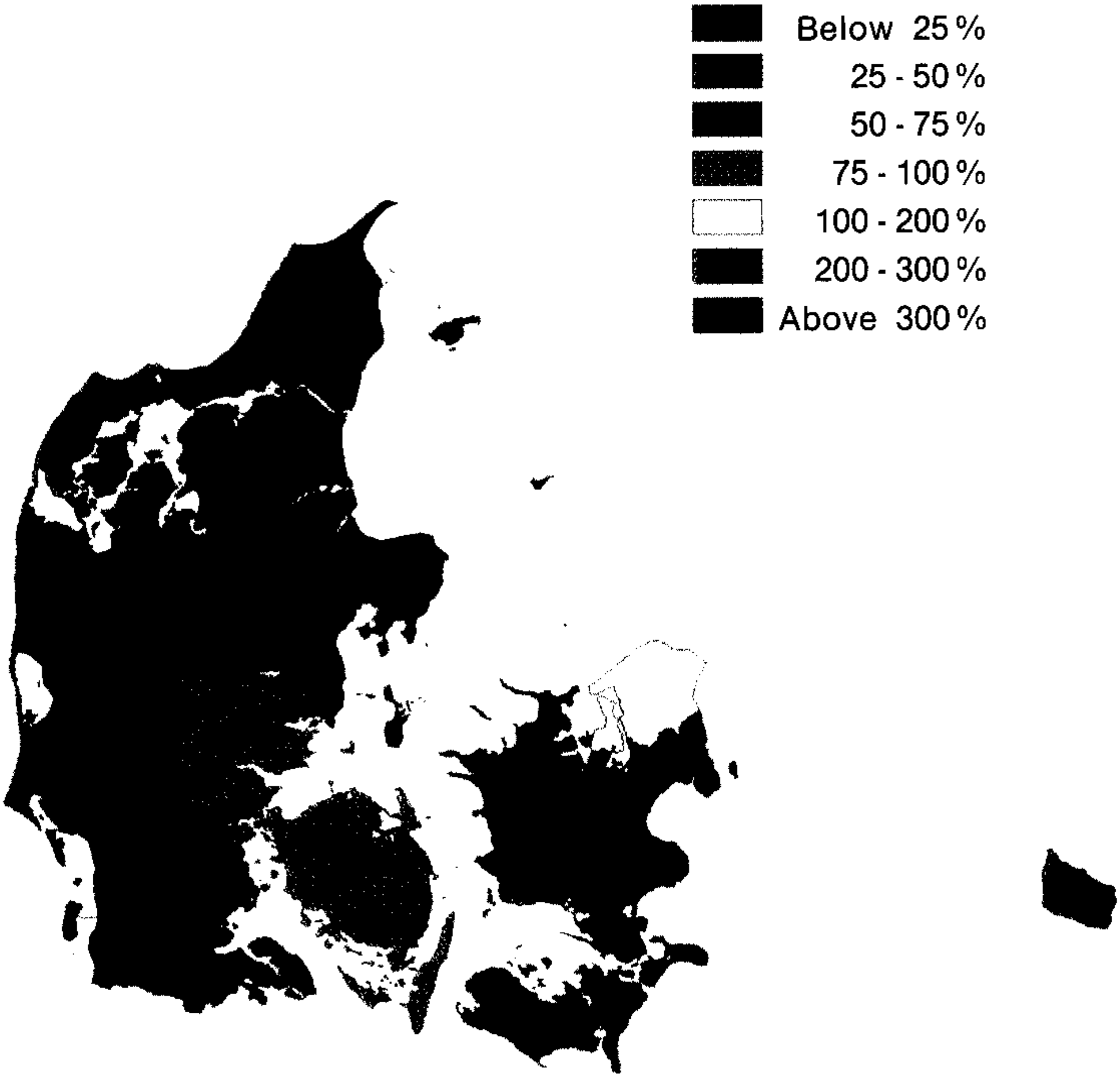

Figure 5.3 **Utilization percentage of the available water resource. The available resource is calculated by i.a. taking into consideration the minimum requirements of the flow of the water courses.** (The Water Council, 1990).

Coefficient of utilization of the ground water resource

By this method the actual water consumption on a national basis is calculated to be about two-thirds of the potentially exploitable ground water resource. This national average, however, covers considerable regional differences. The consequences of the actual water consumption is, therefore, decisively different from one region to another.

Regional differences

In the metropolitan region, the ground water resource is today overexploited. It is normally not warrentable, out of consideration to i.a. the flow of the water courses, to utilize more than 10-20% of the newformed ground water, but in the metropolitan area this percentage is much higher. This means that a number of wetlands and watercourses are strongly affected or completely dried out during the summertime.

Parts of the counties of Aarhus, Vejle and Funen are also marked by over exploitation.

County/region	Amount mill. m^3	Consumption mill. m^3	Remaining mill. m^3
Capital region	90	197	-107
West Zealand	82	52	30
Storstrøm	83	52	31
Bornholm	18	6	12
Funen	84	79	5
South Jutland	187	111	76
Ribe	206	109	97
Vejle	171	140	31
Ringkøbing	331	82	249
Århus	173	102	71
Viborg	196	64	132
North Jutland	226	163	63
DENMARK	1.847	1.157	690

Table 5.1

The accessible ground water resource, calculated by taking into account i.a. the water flow of the watercourses, the consumption and the remaining resource in different regions and on a national scale (the Water Council 1990a).

In several counties, water abstraction cause local problems as a result of an inadequate abstraction structure, e.g. by way of placing water borings in the immediate vicinity of watercourses and wetlands.

Remaining resource and pollution

In the calculation of the remaining resources, see figure 5.3 and table 5.1, the quality state of the ground water has not been taken into consideration. An eventual pollution will of course reduce the size of the remaining useful resource.

As examples can be mentioned

Chemical waste

- that in the county of Copenhagen, large parts of the potentially useful ground water resource is either contaminated or exposed to pollution by chemical waste deposits (Copenhagen County 1990b).

Chloride and fluoride

- that in Jutland, in an area from Djursland to Limfjorden, a nitrate pollution can be established presently in relatively large depths, and besides it can be established that large parts of the deep ground water has a naturally poor quality, with high content of i.a. chloride, and in part fluoride, which makes it unfit for water supply purposes. It must be expected that within these areas, by an unchanged nitrate load, increasing problems will occur within a foreseeable future with abstraction of sufficient water of a satisfactory quality. (Counties of Aarhus, Viborg and north Jutland 1990).

»Brown water«

- that in Ribe county, where the ground water resource is generally ample in proportion to the present consumption, parts of the deep ground water are in practice unfit for water supply purposes as a result of a very large content of organic matter (brown water) (Ribe county 1990).

Future abstraction possibilities

The remaining resource of about one-third must thus, if the pollution conditioned and natural limits of the ground water utility are taken into consideration, be evaluated as a narrow framework for future supply-technical and structural solution possibilities, the present water consumption taken into consideration.

5.1.5. Status and development of the water abstraction

Development of water consumption

Water abstraction in Denmark has been strongly increasing up through the 1970's, whereas it has stagnated in the 1980's. However, a continued increase in the permitted abstraction volume for field irrigation has taken place. Total water consumption in 1988 was about 1,150 mill m, see figure 5.4 (Water Council 1990b and Gosk et al. 1990).

The abstraction for field irrigation has been calculated as an estimated mean figure on the basis of the permits granted. This mean figure for the actual consumption is most uncertain as the field irrigation requirement is very dependent on the annual variations in precipitation and choice of crop. In dry years the consumption will by far exceed the volumes mentioned here and thereby further reduce the rate of flow of the water courses.

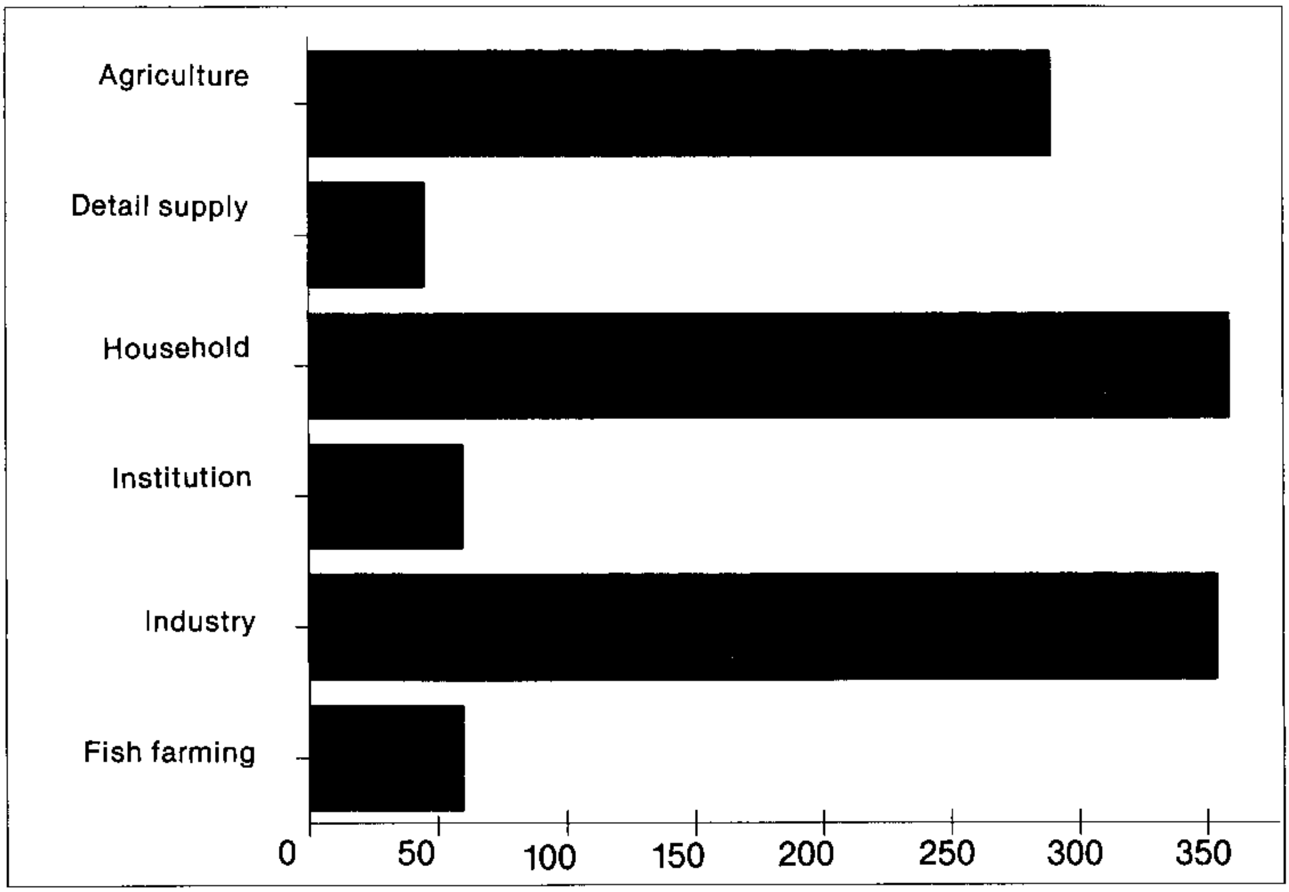

Figure 5.4 **Water Consumption 1988 distributed on categories. In the category »Agriculture« both field irrigation and farm consumption are included.**

Regional trends in water consumption

According to the reports of the counties, the following trends in water consumption can be established:

A stagnation has taken place in water abstractions in the counties of Storestrøm, South Jutland, Vejle, Viborg, North Jutland, West Zealand, Aarhus, Funen, Ribe, Frederiksborg and Copenhagen and in the metropolitan districts of Copenhagen and Frederiksberg.

Water abstraction has increased in the counties of Bornholm and Ringkøbing.

The county of Roskilde does not find that, on the basis of the information available, anything general can be said about developments in the water consumption.

On a national level a continued stagnation in the water abstraction can be expected.

5.1.6. **Drinking water quality**

With the EEC Drinking Water Directive (80/778/EEC) as base, recommended and maximum acceptable limits have been laid down for the nitrate content of Danish drinking water. Drinking water must as a maximum contain 50 mg nitrate per litre and efforts should be made to ensure that the nitrate content does not exceed 25 mg nitrate per litre.

Water works

Already at the time when the limits were laid down, some water works were not able to comply with the quality requirements. Developments in the nitrate load from agricultural areas mean that the water works will get increasing problems in abstracting drinking water of a satisfactory quality from existing sources and drillings.

Private wells and drillings

The part of the Danish drinking water supply, which is based on about 130,000 single plants (private wells and drillings), generally has considerable problems in complying with the quality requirements. Plants of this type typically abstract from ground water reservoirs very close to the surface and are therefore particularly vulnerable to nitrate pollution. In counties, where more systematic studies of the water quality are carried out, it appears that 50 – 75% of the individual plants supply drinking water with more than 50 mg nitrate per litre, or water which is contaminated by bacteria (i.a. Ground Water Monitoring, Vejle County 1990).

Rearranges of the water supply

In recent years, it has therefore been necessary for the water works and the local authorities to implement a number of technical changes of the water supply with a view to ensuring a drinking water quality which – as a minimum – can comply with the maximum acceptable limit for nitrate content.

In practice, this has meant that abstraction borings with a high content of nitrate have either been given up and replaced by new ones, or that a mixing of water from different boring are carried out before distribution to the consumers.

It has been tried to solve the quality problems of individual water supplies by an extension of the common water supply in the rural areas. Intensified efforts must be expected in this area in coming years.

Nitrate content in drinking water Status and development

In figure 5.5, a comparison is made of the drinking water quality from water works with an annual abstraction of more than 10,000 m in 1981/82 and in 1986/88.

The data bases of the two periods are not completely alike which means that development trends must be interpreted with caution.

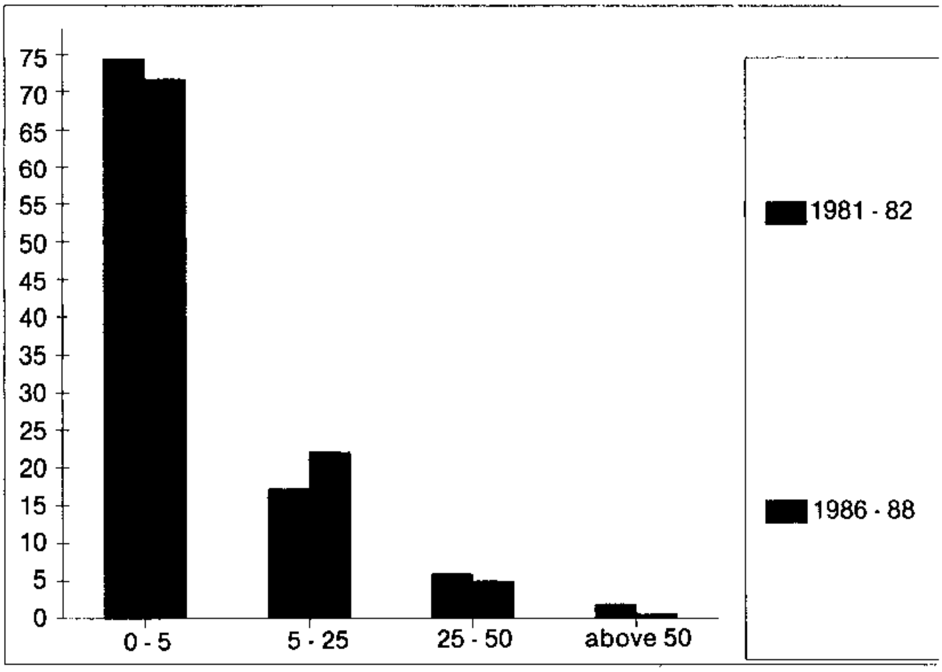

Figure 5.5 **The nitrate content in drinking water in mg per litre, distributed on concentration intervals for the years 1981-82 and 1986-88, respectively.**

The present status shows that more than 99% of the drinking water supplies from water works comply with the maximum acceptable limits for nitrate of 50 mg per litre. 94% of the drinking water complies with the recommended limit of 25 mg nitrate per litre.

The quality of drinking water from Danish water works must, with respect to content of nitrate, on the whole be said to be satisfactory, and the most acute quality problems may largely be delimited to the approx. 5% of the population who are presently supplied from own wells and borings.

The improvement of the drinking water quality from 1981/82 to 1986/88 has first and foremost been achieved through an effort in the water works with the highest loads of nitrate. During the period concerned a halving has taken place of both the number of water works and of the volume of supplied drinking water exceeding the limit of 50 mg nitrate per litre.

At the same time, it can, however, be established that the part of the drinking water supply which is in fact unaffected by nitrate (0-5 mg per litre) during the period constitutes a falling share, and that the volume of drinking water affected by nitrate (more than 5 mg per litre) is increasing.

5.2. Watercourses

5.2.1. Spring-fed brooks

Monitoring of springs in 1989

The monitoring of Danish springs in 1989 comprised 60 localities, evenly distributed over the country. Developing trends are evaluated based on measuring made by the country of North Jutland, Aarhus county and The National Environmental Research Institute.

The rate of flow as well as the content of nitrogen and phosphorus in the studied springs varied much from one spring to another. The springs of Jutland generally had large rates of flow with an average of 4 litres per second. The springs in the islands had much smaller rates of flow, on average 0.3 litres per second.

The use of the surrounding area seems to have a great impact on the nitrate concentration in spring water. Thus, about 90% of the springs in natural areas contain less than 2 mg nitrate-N per litre. Also, it seems that the content of phosphorus is lower in springs situated in natural areas than in areas affected by cultivation (figure 5.6).

Previous studies of the chemical water quality in springs in Jutland (Rebsdorf and Thyssen 1986, Andersen et al. 1990) have shown a very great variation, with regard to the general characterization (pH, dissolved salts and iron compounds) as well as with regard to concentrations of nitrogen and phosphorus. This is also true of the springs which are included in the nationwide monitoring programme, where especially the content of nitrate is clearly correlated to the use of area (figure 5.6).

Time flow charts

By studying time flow charts of the content of nitrate, an increase of nitrate has been established in five out of six studied springs in Jutland (Kristensen et al 1990). With regard to phosphorus, no clear tendency of change in the concentration has been found. However, there is a tendency that the phosphorus content is higher in areas affected by cultivation. In springs in cultivated areas, the level is 0.06 – 0.1 mg P per litre, whereas in natural areas it is 0.03 – 0.06 mg P per litre.

5.2.2. Biological conditions of watercourses

Biological evaluation of watercourses

The biological state of Danish watercourses has to a varying extent been studied since 1970. The evaluation has been made on the basis of the composition of species and the amount of the different small animals (macro-invertebral) which mainly live on the watercourse bottom (Ministry of Agriculture 1970). The method applied is primarily fit to separate strongly polluted watercourses from less polluted watercourses. Since the beginning of the 1980's, the counties have changed the method for evaluating the biological state of watercourses, as a consequence of improved knowledge of animal life and the publication of the so-called Viborg-index (Andersen et al. 1982). However, several counties in the evaluations still use parts of the elements of the former method.

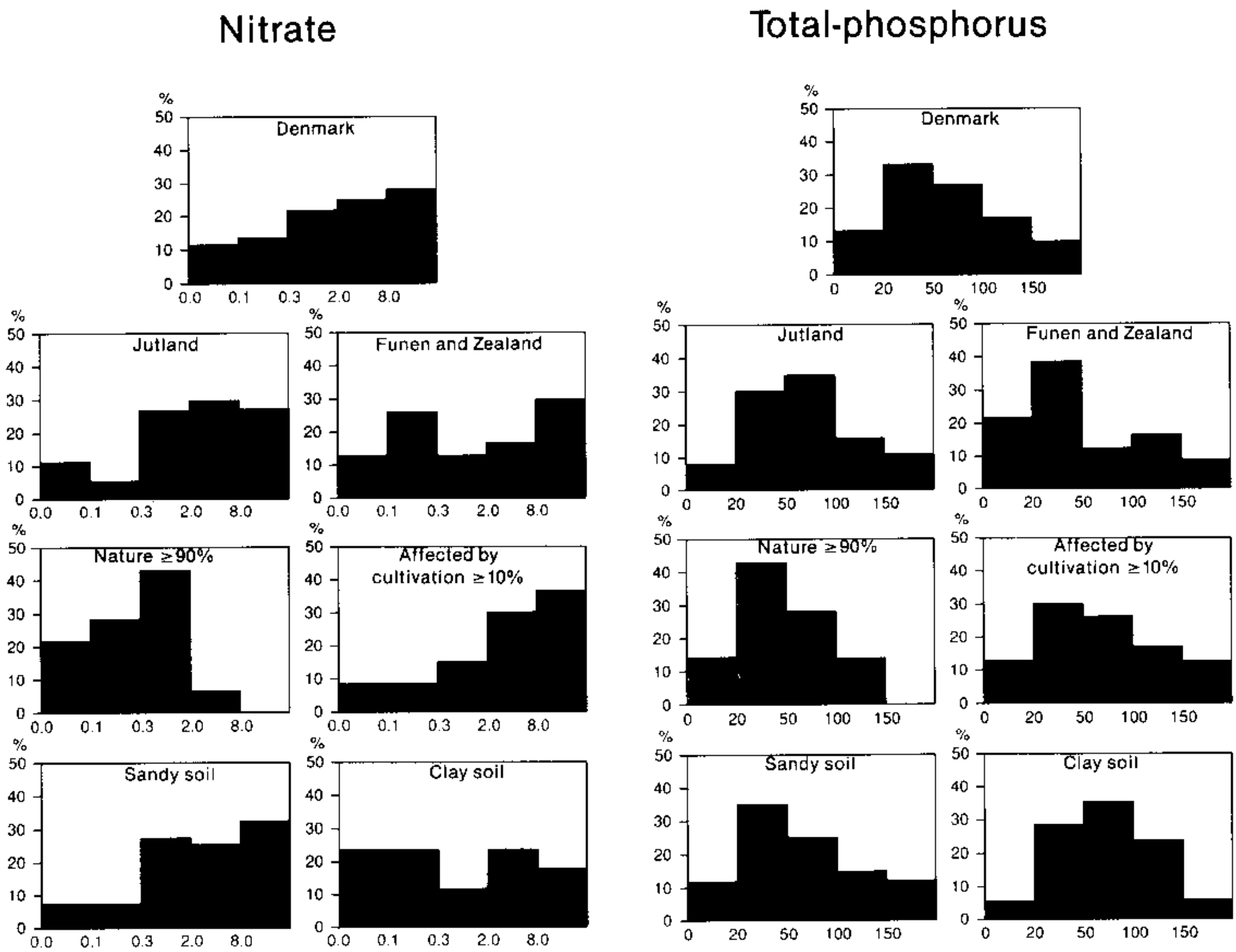

Figure 5.6 **Distribution of the concentration of nitrate, mg per litre and total phosphorus, μg per litre in the springs according to geographical location, use of area and dominating type of soil (Kristensen et al. 1990b).**

Biological evaluation of watercourses in 1989

The biological evaluations of the counties in 1989 appear from figure 5.7. Compared to the requirements for fulfilment of the objectives for the watercourses, see table 3.1, it can be ascertained that in 36% of all evaluations, the unacceptable pollution degrees III, III-IV and IV have been found, meaning that the objectives have not been reached. Regarding the evaluations, where pollution degrees II-III (30%) was found, the objectives can only be considered as having been reached in 1989 if the evaluated locality was situated at stretches of watercourses with eased objectives (see table 3.1).

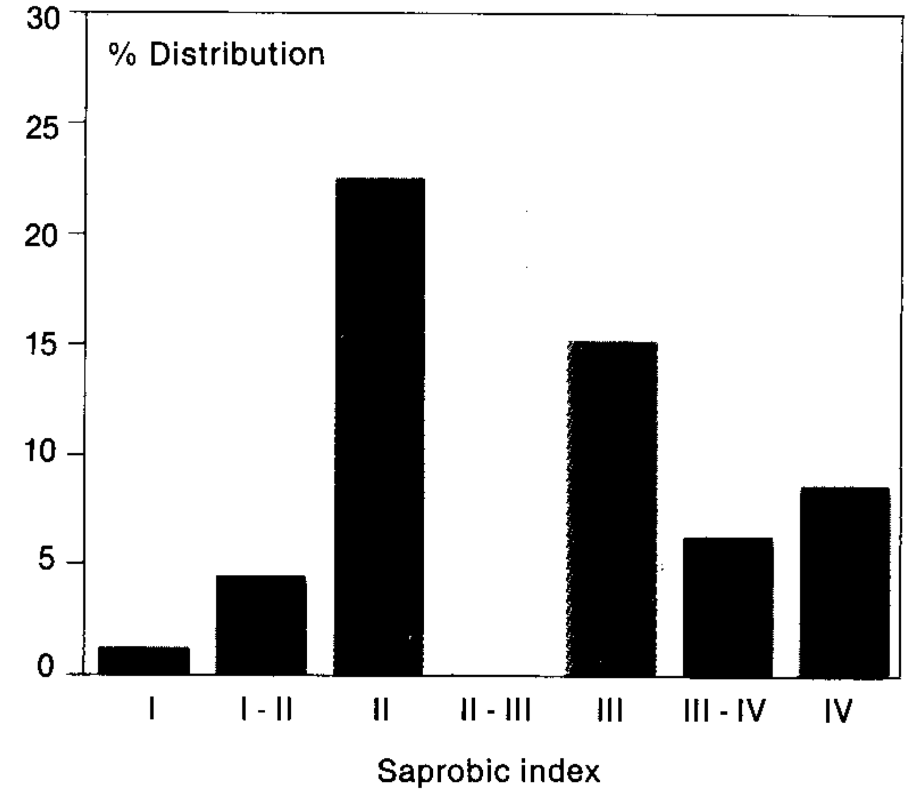

Figure 5.7 **Distribution of saprobic index's in the biological evaluations of watercourses carried out by the counties in 1989.**

The environmental state of the watercourses is thus generally considerably worse than the desired state, as it appears from the regional and recipient quality plans of the counties. This is confirmed also by the latest reports issued by the counties.

County of Ringkøbing

In a report on the state of the watercourses in Ringkøbing county in 1989, it is shown that the share of rather slightly to rather strongly polluted watercourses has gone up significantly from 13% in 1984 to 25% in 1989. In turn, the share of clean watercourses has fallen 5%, and the share of watercourses with a strong load of ochre has been reduced by 7%. There are just as many strongly polluted watercourses in 1989 as in 1984. To summarize, no positive development in the state of pollution has been observed since 1984 (Ringkøbing county 1990). The much polluted parts of watercourses have in general been found in the small watercourses and the watercourses with load from fish farms. The main courses of the streams Skjern stream and Karup stream have been evaluated practically non-polluted.

County of Frederiksborg

In the county of Frederiksborg less than 10% of the watercourses in 1988 fulfilled the objectives. It was found that compared to 1985, however, a positive development could be seen, as the number of polluted watercourses had declined (Frederiksborg County 1990).

County of Storstrøm

In the county of Storstrøm, in spite of a considerable effort to stop illegal discharges from farms and the introduction of compulsory schemes to empty domestic sewage tanks outside the sewaged areas, no clear improvement was found in the state of the watercourses at Lolland, Falster and Møn. It has been found that there is a need for further treatment of the waste water from sparsely built-up areas and for a more environmentally desirable watercourse maintenance (Storstrøm County 1990).

Other counties

Reports on the state of watercourses in other counties in general show the same trends as the reports from the counties of Ringkøbing, Frederiksborg and Storestrøm. However, it must be pointed out that all over the country examples can be found of watercourse systems, where improvements have been acheived. The reason for this has been important changes in the input of waste water and in the watercourse maintenance, and eventually watercourse restorations.

5.2.3. **Transportation and concentration of substances in Danish watercourses**

Transportation of substances

In 1989, transportation of nitrogen and phosphorus in the watercourses was measured by linked values of water flow and concentration of substances. The station network of the Action Plan for the Aquatic Environment is selected so that the stations can be included in an evaluation of the influence from agriculture, fish pond farms and treatment plants on the total load of watercourses, lakes and the sea.

Method of statement

The statement of the load from point sources has been made either on the basis of actual measuring or on the basis of figures of experience (Kristensen et al. 1990b). The contribution from the open land has been calculated as the difference between measured total transportation and discharges from point sources (see figure 5.8). The contribution from the open land consists of inputs from natural areas, from cultivated land, from farms and from other sparsely built-up areas.

Nitrogen

The runoff of nitrogen (areal coefficient of N) from the selected catchment areas was between 8-16 kg N per ha per year (figure 5.9). The average concentration was in most watercourses larger than 4 mg N per litre. The rate of flow-weighted concentration was higher than the annual mean concentration, which is due to the fact that in many watercourses there is a positive connection between rate of flow and concentration of nitrogen. In periods with high rate of flow, the concentration is therefore higher.

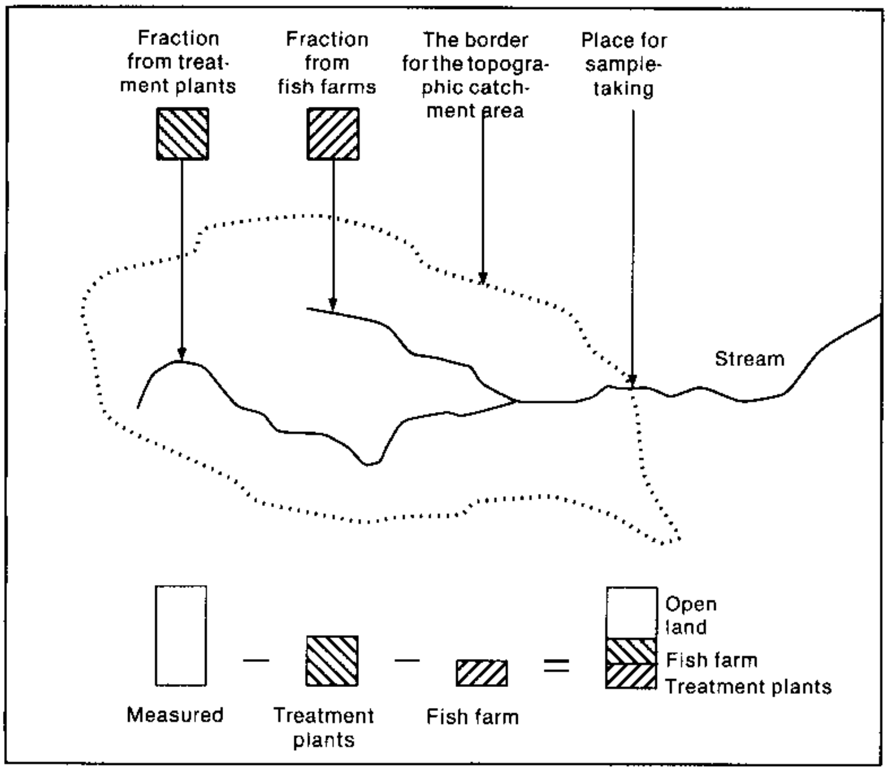

Figure 5.8 **Principal sheet for division of sources in the Action Plan for the Aquatic Environment.**

The runoff of phosphorus (P) varied between less than 0.1 kg P per ha per year and more than 1 kg P per ha per year (see figure 5.9). Most catchment areas had a runoff of between 0.1 and 0.6 kg P per ha per year. The distribution of the annual mean and the rate of flow-weighted concentration of P showed alike, with most watercourses having concentrations between 0.1-0.3 mg P per litre (Kristensen et al. 1990b).

5.2.4. Comparison of typological-catchment areas

Typological catchment areas

In order to show the share of input of nitrogen and phosphorus of the different sources to the watercourses, a comparison has been made of the transportation of substances and the concentration, in as well unaffected catchment areas (reference catchment areas) as in cultivated catchment areas with different inputs of waste water from point sources (Kristensen et al. 1990b). The unaffected catchment areas have, moreover, been compared with catchment areas which are considerably affected by discharges from fish pond farms and treatment plants.

Nitrogen

In a comparison of the runoff and concentrations of nitrogen and phosphorus, respectively, in uncultivated catchment areas and cultivated catchment areas, it can be established that the runoff and the concentration of nitrogen is 3 – 6 times as high in the cultivated catchment areas (table 5.2).

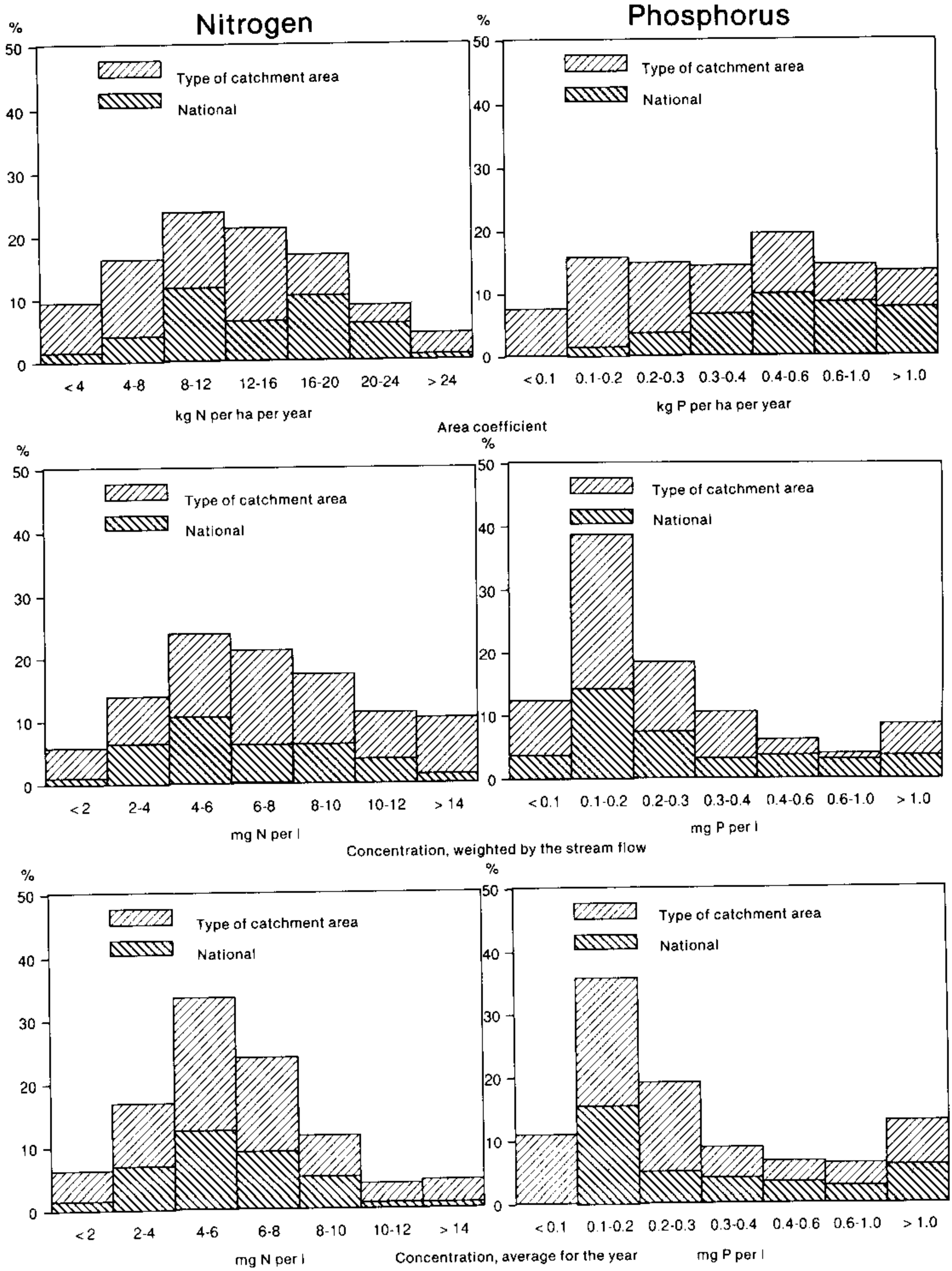

Figure 5.9 **Percentage distribution of runoff (areal coefficient), rate of flow weighted and annual mean concentration of nitrogen and phosphorus at 250 national stations and typological catchment areas - the monitoring programme of the Action Plan for the Aquatic Environment.**

In 1989 the runoff of nitrogen from cultivated areas was on average 13 kg per ha per year and similar in both sandy and clay soil. On the basis of the average for the 1980's, the runoff in a normal year is estimated to 20-24 kg N per ha per year in sandy soil and 25-30 kg N per ha per year in clay soil.

In connection with studies of six special land monitoring catchment areas the nitrogen leaching from the root zone for 1989 has been calculated (Blicher-Mathiesen et al. 1990).

	Areacoefficient kg N per ha per year		Concentration weighted by stream flow mg per litre	
	average	median	average	median
Reference catchment area	2,9	1,9	1,9	1,6
Cultivated catchment area:				
without individual sources	11,6	9,3	7,1	5,8
small individual sources	14,1	12,8	7,9	7,2
included fish farming	13,4	12,6	3,4	3,4

Table 5.2

Collocation of nitrogen runoff and concentration in 1989 in watercourses from reference catchment areas and cultivated catchment areas, without and with small point sources, and with load of fish farms (according to Kristensen et al. 1990b).

The leaching from a sand soil catchment area has been calculated to 78 kg N per ha per year, and for clay soil catchment area to 41 kg N per ha per year. These values are considerably higher than the areal coefficients of around 13 kg N per ha per year. This shows that only part of the leached nitrogen from the root zone flows to the watercourses.

Phosphorus

Concerning phosphorus, the runoff and concentration are 3 – 4 times as high in cultivated catchment areas without point sources as in the reference catchment areas. The higher values are partly due to farming and partly to contributions from sparsely built-up areas. The distribution between the two sources is not known. (See section 4.1.4.).

The area coefficient and concentration of phosphorus were much higher in watercourses receiving input from fish farms or from treatment plants (table 5.3).

	Areacoefficient kg P per ha per year average	median	Concentration weighted by stream flow mg per litre average	median
Reference catchment area	0,07	0,05	0,06	0,06
Cultivated catchment area	0,27	0,21	0,16	0,14
Catchment area for fish farms	0,76	0,78	0,17	0,18
Catchment area for waste water	1,46	0,44	1,12	0,33

Table 5.3

Collocation of runoff and concentration of phosphorus (P) in 1989 in watercourses from reference catchment areas, cultivated catchment areas and catchment areas with loads from fish farms and effects of waste water (according to Kristensen et al. 1990b).

5.2.5. Development trends in concentration and transportation of nitrogen in Danish watercourses

Development up till now of concentration and transportation

In order to make an evaluation of the reasons, including the importance of the individual sources, for the environmental state established in lakes and the near-shore and open marine waters, it is important be able to describe the earlier development in concentration and transportation of nitrogen in Danish watercourses.

The main part of nitrogen in watercourses stems from leaching from agricultural soils as a result of fertilizing with commercial fertilizers and animal manure.

In an analysis of measurings from 62 watercourses in West and East Jutland and Funen, it has appeared that the nitrogen concentration level in the watercourses has been rather constant during the period 1978/79 to 1988/89 (Kristensen et al. 1990b).

During the period 1967/68 to 1978/79, there has been an increase of about 2.5% in the concentration of nitrogen measured as nitrate in the streams Skjern stream, Gudenå and Odense stream (figure 5.10). A similar increase of about 3% per year has taken place in the runoff of nitrogen in these watercourses (Kristensen et al. 1990b).

5.2.6. Total transportation of nitrogen and phosphorus in Danish watercourses

Transportation of nitrogen and phosphorus in the watercourses in 1989 has been calculated on the basis of measuring at the 130 national watercourse stations spread geographically all over the country. With respect to catchment areas, they cover about 50% of the area of Denmark (Kristensen et al. 1990b).

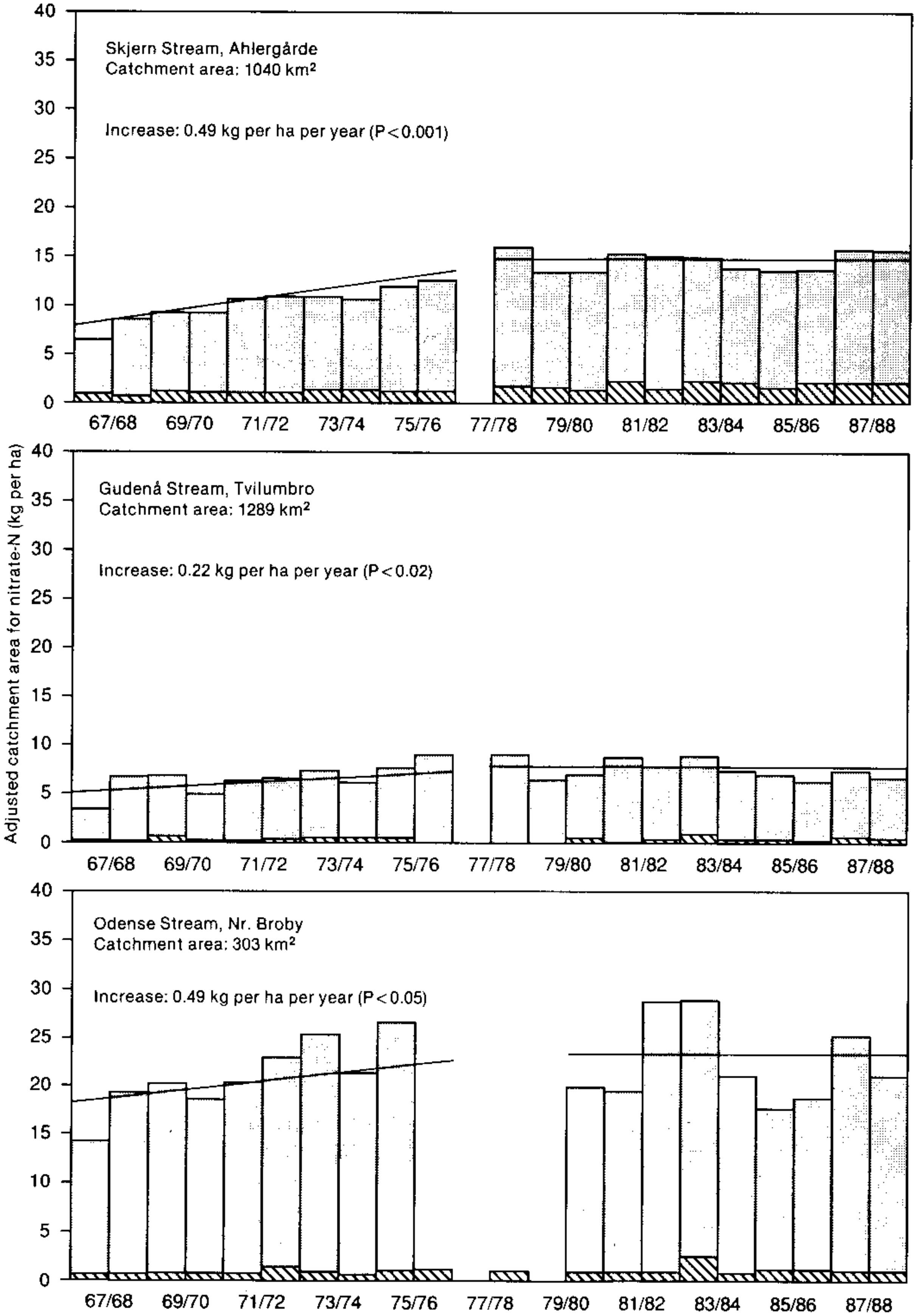

Figure 5.10 **Runoff-adjusted area runoff of nitrate-nitrogen in the years 1967/68 to 1988/89, and increases in the years 1967/68 till 1978/79 in the streams Skjern stream, Gudenå and Odense stream** (Kristensen et al. 1990b).

Climatic conditions

The climatic conditions in 1989 have been unusual compared to previous years. With regard to temperatures, it was a very mild and sunny year. Therefore, evaporation was rather pronounced. Precipitation at the same time was 24% below the mean value of the preceding eight years. Runoff from watercourses of 11,000 million m constituted 68% of the mean of the preceding years.

Runoff

On the basis of catchment area-weighted average for the runoff during the period 1981-89 in the streams Skjern stream, Gudenå, Odense stream and Susâ, the total runoff from Denmark in a »normal year« can be estimated to about 16,200 million m.

Total input into the sea

Input of nitrogen and phosphorus in 1989 from the watercourses into the sea divided on the 9 main water areas is shown in table 5.4.

	Area km^2	Nitrogen tonnes	Phosphorus tonnes
1. The North Sea	10.888	15.425	599
2. Skagerrak	1.060	1.673	88
3. Kattegat	15.824	24.154	963
4. The North Belt	3.178	4.784	336
5. The Little Belt	3.310	5.340	328
6. The Great Belt	5.466	6.635	279
7. The Sound	1.730	1.627	200
8. The South Belt	428	467	15
9. The Baltic Sea	1.208	1.778	54
Total	43.092	61.883	2.862

Table 5.4

Input of nitrogen and phosphorus via watercourses to the 9 main water areas and totally in 1989 (According to Kristensen et al. 1990b).

The percentage share of the annual nitrogen and phosphorus input to the watercourses, which takes place during the summer period (May-September), is shown in figure 5.11. Input of phosphorus to the 9 main water areas varies during this period only between 19 and 34%. But the input of nitrogen varies a lot, with the largest amount in the waters with catchment areas in West and North Jutland (about 20%), and with less than 5% to the waters with catchment areas in South Zealand.

5.2.7. Transportation of nitrogen and phosphorus in the watercourses in a »normal year«

Transportation of substance in a »normal« year

As mentioned earlier, 1989 was a most atypical year with regard to evaporation, precipitation and thereby runoff in the watercourses. Similarly, the transportation in the watercourses of nitrogen and

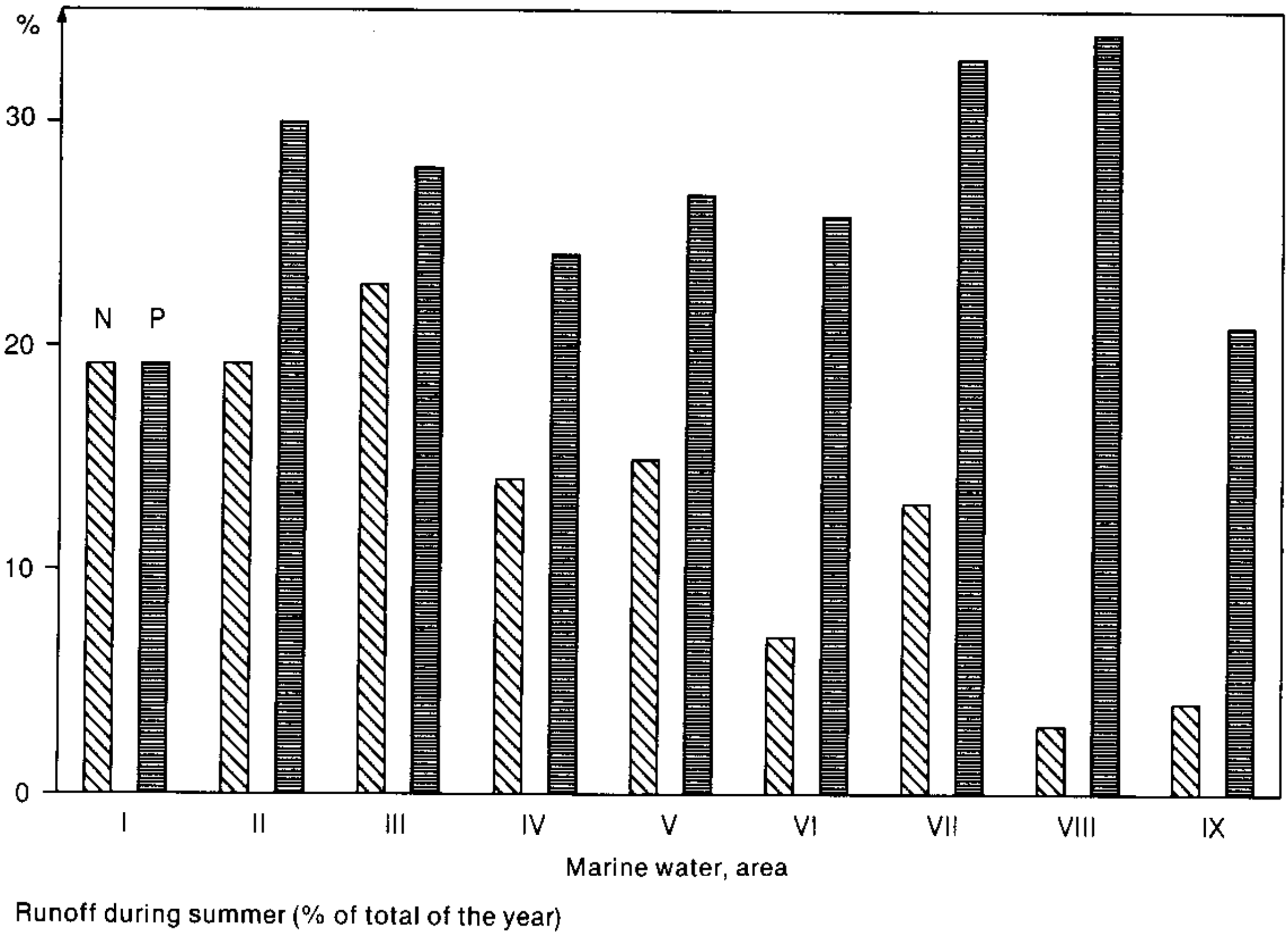

Figure 5.11 **Transportation of nitrogen and phosphorus via watercourses to the nine main water areas during the summer period (May-September) in percentage of the annual input.**

phosphorus was much lower than it was on average in the period 1981 to 1989 (Kristensen et al. 1990). Thus the runoff of nitrogen was about 57% of the mean value of the preceding eight years, and the runoff of phosphorus about 54%, as an average for four watercourses (figure 5.12). The deviation for nitrogen from the mean value is largest for the watercourses in East Denmark. The deviation for phosphorus is more or less the same all over the country.

Transportation of nitrogen and phosphorus in the watercourses in a »normal year« may therefore be calculated on the basis of the 1989-level with respect to discharges from point sources and a revaluation of the contribution from open land. The contribution from open land in a »normal year« is calculated on the basis of the average deviation found in four large watercourses.

110,000 tons nitrogen and 4,200 tons phosphorus

The transportation in all watercourses in a normal year has on this basis be calculated to around 110,000 tons nitrogen and 4,200 tons phosphorus.

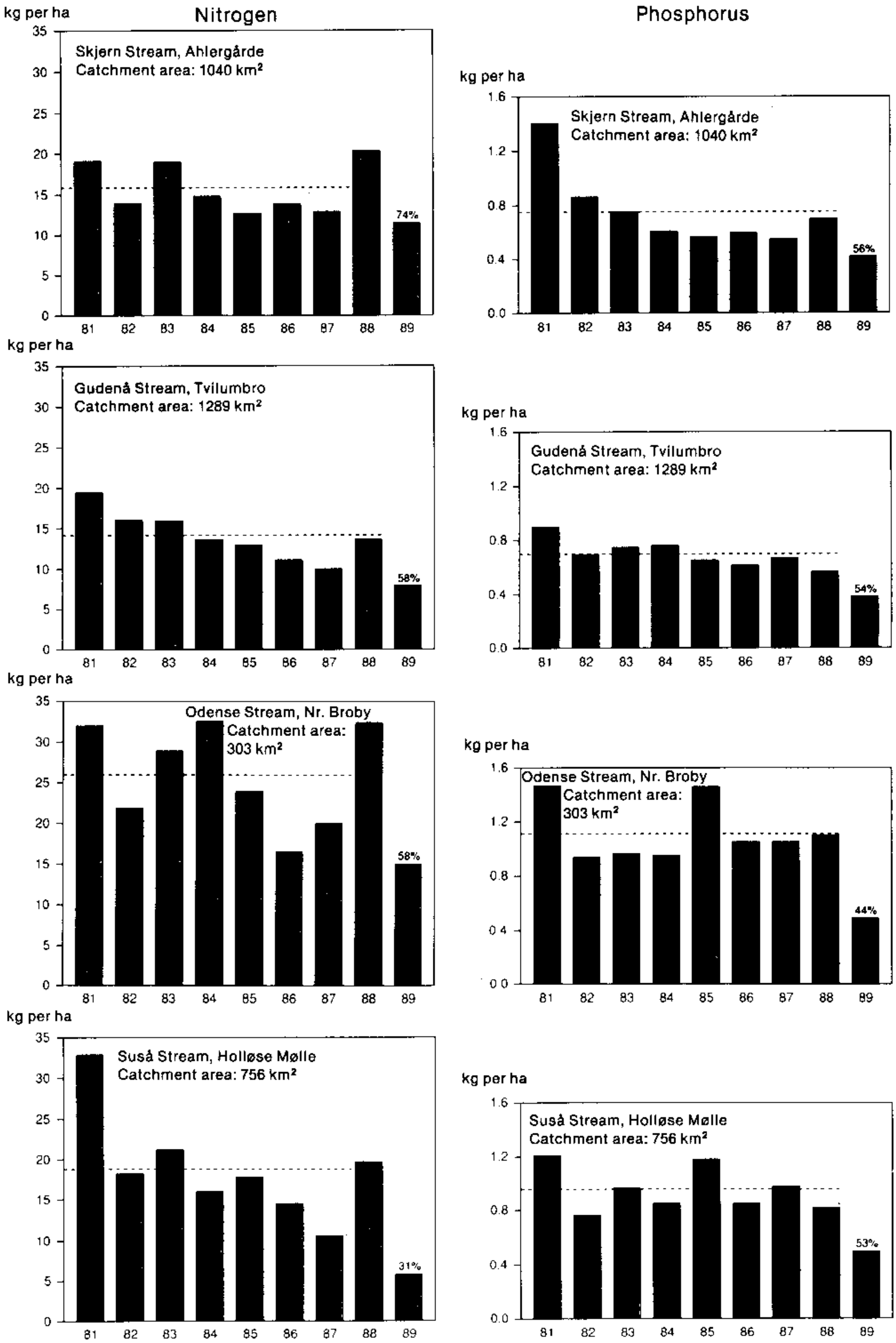

Figure 5.12 **Runoff of nitrogen and phosphorus measured in the period 1981 till 1989 from four large watercourse catchment areas. The signature --- shows mean value for the period 1981 till 1988.**

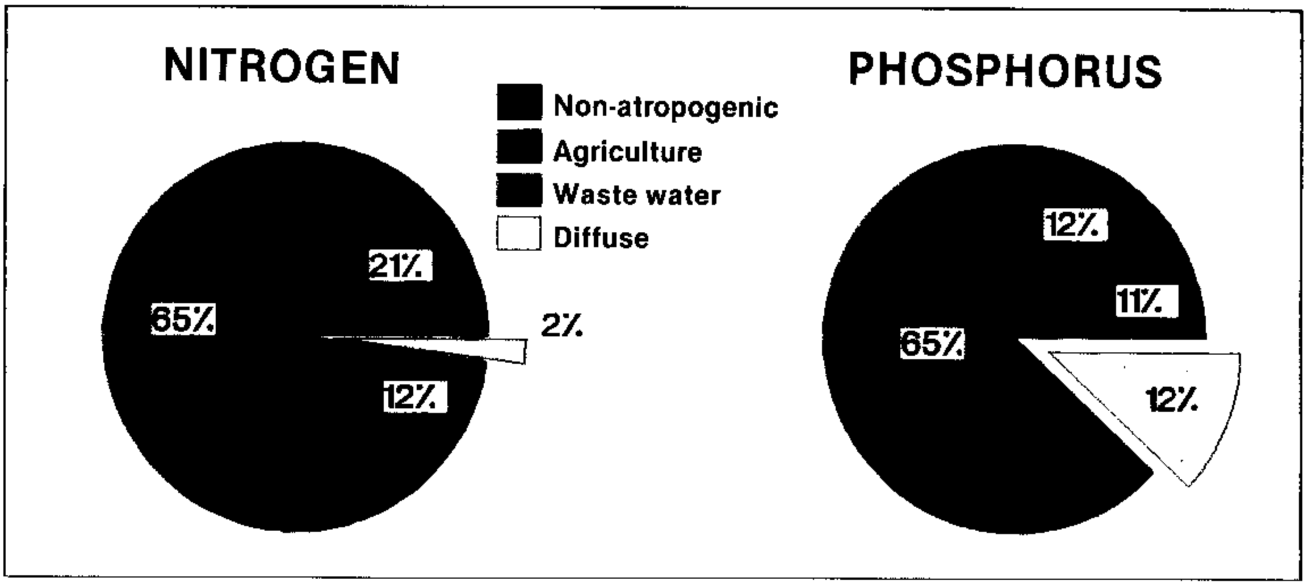

Figure 5.13 **The percentage share of nitrogen and phosphorus input in watercourses in 1989 from point sources, sparsely built-up areas, non-atropogenic and farming.**

5.2.8. Conclusion and evaluation of the state of Danish watercourses

Biological state

Studies of the state and development of Danish watercourses show that the environmental goal was fulfilled for about 34% of the studied watercourses in 1989. The biological state was not acceptable in 36% of the evaluated watercourses, and the state was »critical« in the remaining about 30%.

There is much to indicate that it is especially in the smaller watercourses that the biological state has not improved.

The addition of nitrogen and phosphorus to springs and watercourses is larger from areas affected by cultivation than from natural areas.

Nitrogen

Nitrogen comes mainly from areas affected by cultivation, and phosphorus mainly from treatment plants and fish farms (see figure 5.13).

Phosphorus

The contribution of phosphorus from cultivated areas and sparsely built-up areas cannot be separated. Finally, it can be established that the contribution of phosphorus from cultivated areas and sparsely built-up areas will get a relatively larger importance when the reductions from the larger treatment plants have been carried out in accordance with the Action Plan for the Aquatic Environment.

5.3. **Lakes**

350 Danish lakes

The present environmental state of Danish lakes may be estimated on the basis of information obtained about the physical-chemical and biological conditions in 350 lakes. In the evaluation is included information obtained from the counties and results from intensive studies in a smaller number of lakes, primarily carried out by the National Environmental Research Institute.

The Danish lakes are generally very rich in nutrients, with high concentrations of nitrogen and phosphorus in the lake water. This means high biomass of plant plankton and thereby unclear water and poor secci depth (table 5.5).

	Average	Mean	Max.	Min.
Total Phosphorus (mg P per l)	0,302	0,146	10	0,008
Total Nitrogen (mg N per l)	2,97	2,12	15,9	0,29
Chlorofyll a (mg per l)	0,080	0,054	0,601	0,0002
Secci depth	1,21	0,91	6,3	0,2
Suspended matter (mg per l)	18	12	130	1

Table 5.5

Survey of nutrient level, chlorophyll content in plant plankton, secci depth and amount of suspended matter in Danish lakes (according to Kristensen et al 1990b).

Phosphorus

The phosphorus level was thus 0.3 mg P per litre on average for all studied lakes and the median 0.146 mg P per litre, whereas the phosphorus content was below 0.020 – 0.040 mg P per litre in natural areas.

Nitrogen

The nitrogen level was on average 3 mg N per litre and the median 2.1 mg N per litre for all lakes studied, whereas in lakes in natural areas it was typically below 0.5 – 1 mg N per litre.

Chlorophyll

On account of the very high nutritious level, the chlorophyll level was very high with a mean and median value which were 5 – 20 times larger than the level in lakes in natural areas.

Secci depth

The secci depth varies between 0.2 and 6.3 m, but as a result of a generally large biomass of plant plankton and the high content of substances in the water, the secci depth was usually low with a mean value of 1.2 m and 0.9 m. The secci depth was especially low in shallow lakes, which are heavily loaded, and besides much affected by poor light conditions from re-whirled material from the bottom. (Kristensen and Jeppesen 1988).

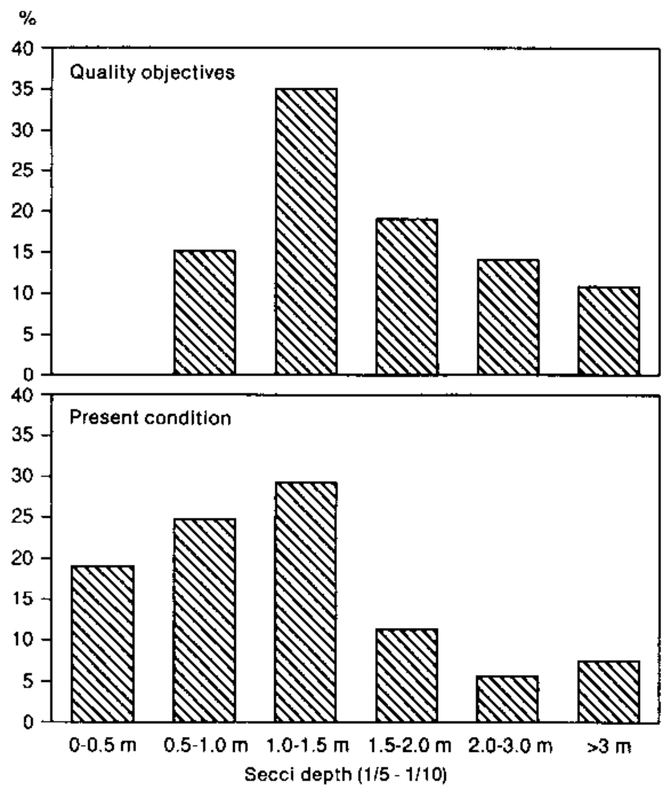

Figure 5.14 **Comparison between the actually measured summer secci depth and the minimum requirements of the recipient quality plans. The comparison is based on a total of 95 lakes from the counties of North Jutland, Aarhus, Vejle and Storstrøm** (Kristensen et al. 1990b).

These results compared with the limits laid down in the regional and recipient quality plans of the counties thus show that the state of the lakes is much poorer than desired (figure 5.14).

5.3.1. Development in the state of the lakes

On the basis of information about the state of Danish lakes from the 1970s (1972-79) and the end of the 1980s (1985-89) an evaluation has been made of the development in the state of the lakes (figure 5.15) (Kristensen et al. 1990b).

Concentration of phosphorus

By analyzing the information obtained, it can be established that there has been a fall in the phosphorus concentration. In the 55 lakes, which are included, the median phosphorus concentration has been reduced from 0.24 to 0.18 mg per litre.

Depth visibility

Despite a fall in the phosphorus concentration by on average 17%, there is, however, no clear tendency of improved depth visibility.

The reason for this is that the phosphorus concentration in many lakes, also after the reduction in the phosphorus input, is higher than the level under which a significant improvement may take place in the secci depth.

Delayed improvement

For some lakes, the lack of improvement of the state may, however, be due to a delay, which is a result partly of an internal load, i.e. release of phosphorus from the pool in the sediment which has accumulated while the load of the lake was highest, and partly of an inertness in the biological system (Jeppesen et al. 1990, Kristensen et al. 1990a).

Possible measures

Therefore, in some cases there may be a need for measures against the liberation of nutrients from the sediment or interventions in the biological system, especially with regard to fish.

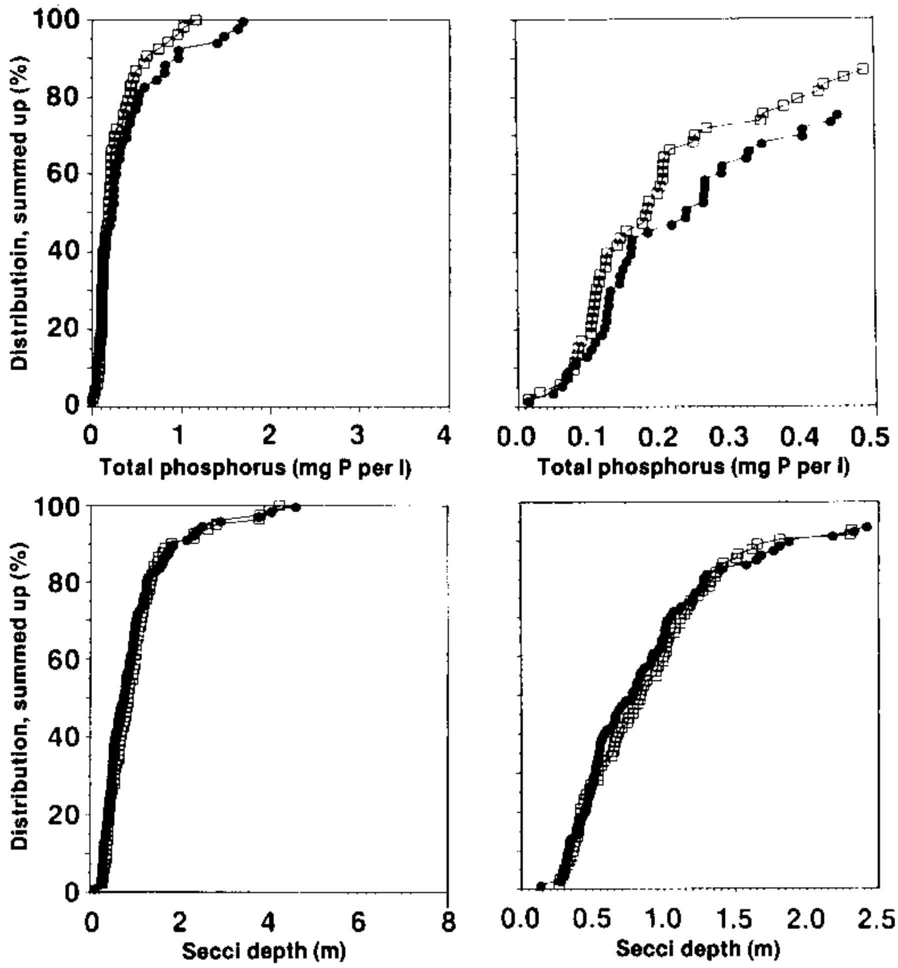

Figure 5.15

Summarized distribution of P-concentration and secci depth in the period 1972-79 (° - °) and 1985-89 (• - •) in all lakes from which information is available from both periods. In the right hand column a smaller part of the left column is up-scaled. The figure is to be understood so that in 100% of the lakes e.g. concentration of phosphorus in 1985-89 was less than 1.2 mg P per litre, in 50% of the lakes the P-concentration during the same period was both less and higher than 0.18 mg P per litre and in 25% less than 0.11 mg P per litre etc. (Kristensen et al. 1990b).

No improvement in secci depth

It can thus be established that the phosphorus level in the lakes has fallen from the 1970s to the end of the 1980s, but that on the whole, no noticeable changes have taken place in the transparency of the water.

5.3.2. Possibilities of improvement of the state of the lakes

Relation between phosphorus concentration and secci depth

On the basis of the knowledge of the connection between load and phosphorus concentration and the connection between phosphorus concentration and the secci depth of the water, models can be made to show which reductions in the input of nutrients to the lakes have to take place in order to improve the state of the lakes (Kristensen et al. 1990b). The evaluations have been made on the basis of the results from the monitoring of 37 lakes in 1989.

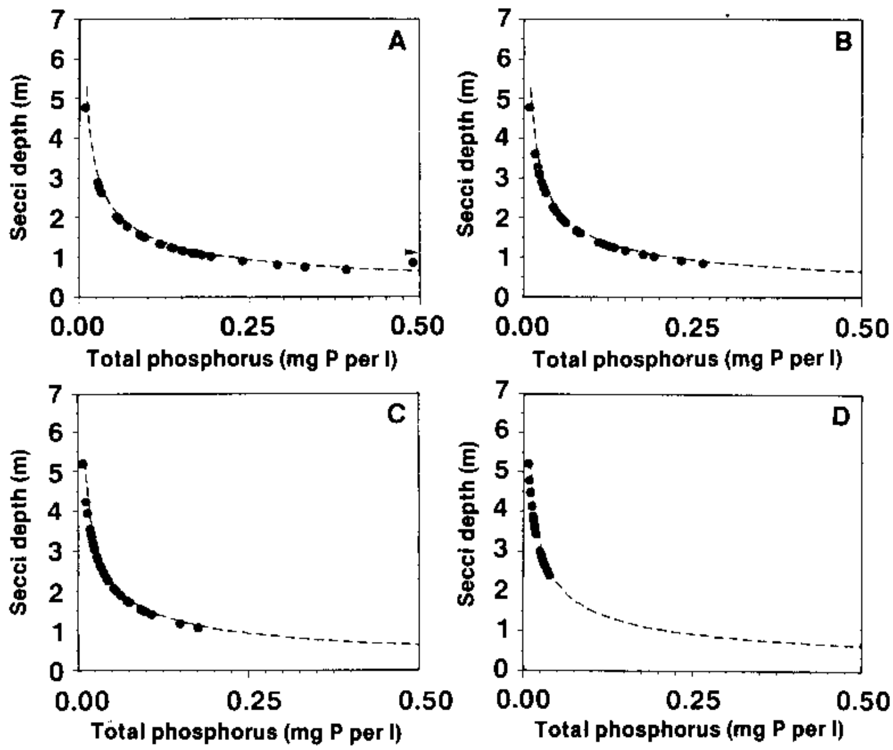

Figure 5.16

Evaluation of the consequences of different initiatives towards the P-input on the concentration of lake water and thereby the secci depth of the water in 37 lakes. In the calculation, the Vollenweider-relation and a simple relation between summer secci depth and the phosphorus concentration have been applied (Kristensen et al. 1990a).

A: Present load (1989)

B: As A, but without point source contribution.

C: As B, but with 50% reduction of input from cultivated and sparsely built-up areas.

D: A load corresponding to the level in natural catchment areas in 1989.

Point sources

The consequence of different changes in the input of phosphorus can be seen from figures 5.16 and 5.17. It appears that if all point sources, including rainwater outlets and overflow structures, are cut, the median phosphorus level in the influx water is changed from 0.197.

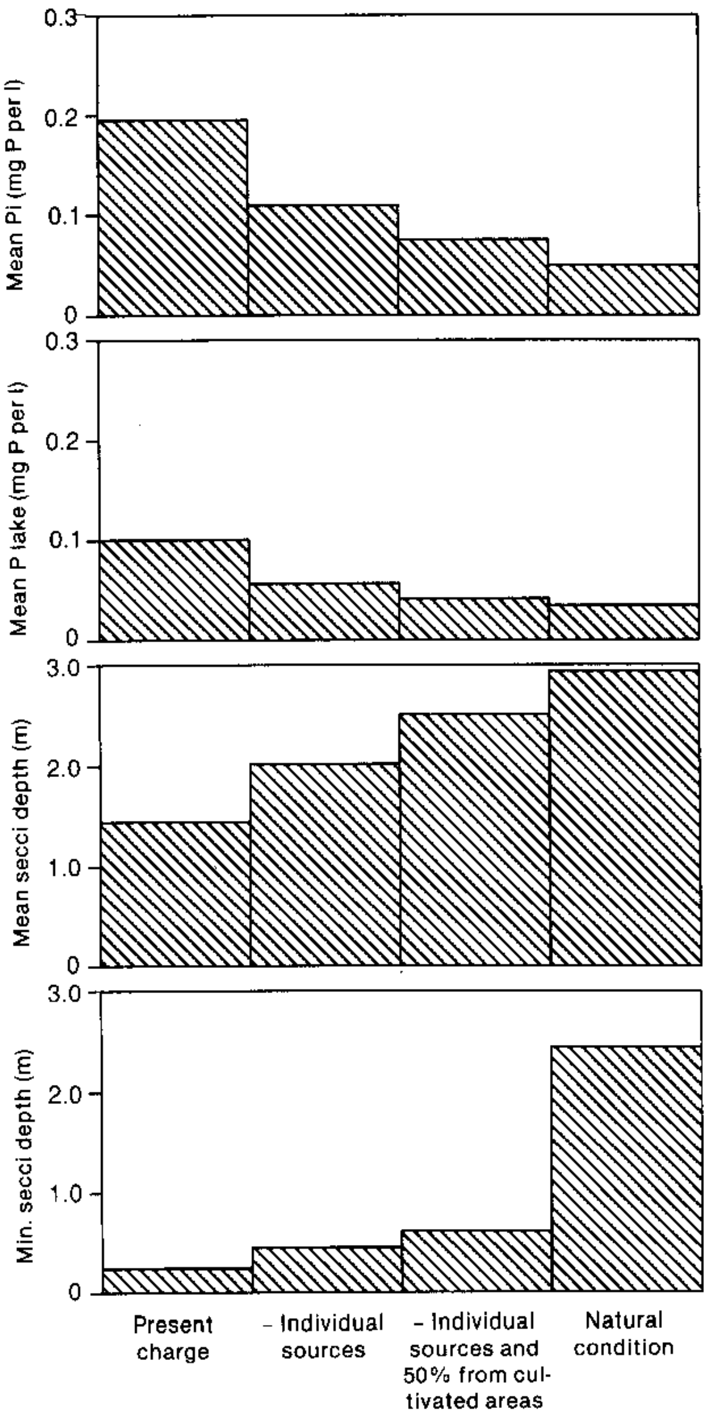

Figure 5.17

Calculated values for the median phosphorus concentration in the influx water (Pi) and in the lake water (Plake), and the median and minimum secci depth in the 37 monitored lakes by different changes in the input of phosphorus (see also figure 5.16).

mg P per litre to 0.133 mg P per litre. Thus the visibility depth will be increased from 1.5 m to 2.0 m. The secci depth will in some lakes still be below 1 m and the lowest secci depth will be as low as 0.5 meters.

Cultivated fields and sparsely built-up areas

If a further 50% reduction of phosphorus input from cultivated fields and sparsely built-up areas takes place, the median concentration in the lakes will fall to 0.058 mg P per litre. By this, the median depth visibility will be increased to 2.5 m and the minimum value to 0.6 m, and only one lake will have a depth visibility of below 1 m.

If the last 50% of the contribution from cultivated areas, including sparsely built-up areas is removed, so that only the background contribution is left, the lake concentration will fall to 0.029 mg P per litre. The secci depth will be increased to a median of 3 m and the minimum value will be 2.5 m.

The requirements according to the Action Plan for the Aquatic Environment set for discharges of phosphorus, of 1.5 mg P per litre in the discharge from treatment plants of more than 5,000 PE, will not as such result in any marked improvements in the state of Danish lakes. Most of these larger point sources have already been cut off from the lakes, or are in the process of being so.

With respect to some treatment plants, located in the catchment area of lakes, which cannot be cut of, requirements are about to be implemented for phosphorus cleaning down to about 0.3 - 0.5 mg P per litre. These requirements often comprise treatment plants down to a size of 200 - 500 PE.

Although effective measures are made against point sources, the evaluations made show that improvements of our lakes will only take place when there has been a marked reduction in the contribution from sparsely built-up areas and cultivated areas.

Conclusion

It can thus be concluded that only a simultaneous reduction of the waste water input and the import from cultivated areas, including waste water supply from sparsely built-up areas, can make the water of Danish lakes clear and fulfil the fixed objectives of a versatile fauna and flora.

5.4. **Marine areas**

The monitoring of the environmental state of the marine areas has since 1974 been carried out by the National Agency of Environmental Protection and the National Environmental Research Institute in the open waters and by the counties in the coastal waters. In the coastal waters, the monitoring has been intensified during the 1980s and with the monitoring programme of the Action Plan for the Aquatic Environment, a nationwide coordinated effort has been established.

5.4.1. **Hydrography and input of nutrients**

The year 1989 was different in climatic terms from the »normal year«, with considerably less precipitation and runoff and other wind conditions. The water exchange between the internal waters and the surrounding waters was in 1989 less than normal. The runoff from

	Nitrogen		Phosphorus	
	1989 Tonnes	81-88 Tonnes	1989 Tonnes	81-88 Tonnes
Streams included waste water	43.000	77.000	2.120	3.000
Direct outlet:				
Municipal plants	9.950	9.950	2.510	2.510
Rainwateroutlet		220		50
Industry	3.000	3.040	330	330
Marine fish farming	300	260	40	40
Denmark (Rounded off)	56.000	90.000	5.050	5.900
Sweden				
Streams included waste water	22.000*	40.500	*	760
Direct outlet	4.400	4.800	500	770
Germany				
Streams included waste water	6.600*	12.500	*	1.950
Direct outlet	>6.300	>6.300	*	>670
Precipation	44.000	48.500	450**	500**
Total (rounded up)	139.000	203.000		10.500

Table 5.6

Annual input of nutrients directly to the internal Danish waters excluding input via sea currents.

* The load in 1989 from Sweden and Germany is only partly known, but is for nitrogen estimated under the same conditions as for the Danish estimates.

** Estimate from the Phosphorus Report (National Agency Environmental Protection 1988).

land to sea was in 1989 much less than in the years 1979-1988, and among the lowest since 1919. This was noticeable first of all in the eastern parts of the country, where the runoff was up to 50% less. As a result of this the marine areas have received significantly lower quantities of nutrients of especially nitrogen, than the mean quantity for the 1980s. In 1989, the input of nitrogen on an annual basis was about 50% less to the internal waters and 25% less to the North Sea.

Nutrients to internal waters

An overall overview of the input of nutrients from all sources to the internal Danish open waters, but without water exchange between the Baltic Sea and the Skagerrak, is shown in table 5.6 (Kristensen et al. 1990b, Leander 1990 and Olson & Löfgren 1990). The input in 1989 is compared with the average input in the years 1981-88.

In addition to the contribution from open land, the runoff via watercourses also includes discharges from waste water sources to watercourses and lakes, as described in section 5.2. The major part of this input is by way of inorganic nutrients which are available for the production of algae. Figure 5.18 shows the distribution of the input from Denmark by the main sources: Open land, waste water treatment plants (indirect and direct discharges) and industry, together with marine aquacultures and fish farms. Figure 5.19 show the distribution of input to internal waters from the three surrounding countries, Denmark, Sweden and Germany for the years 1981-1988.

Nutrients to the North Sea/Skagerrak and the Baltic Sea

The inputs to the North Sea/Skagerrak and to the Baltic Sea are shown in table 5.7, but only as a mean for the 1980s, as the 1989 inputs are known only for Denmark.

	Nitrogen		Phosphorus	
	The North Sea Tonnes	The Baltic Sea Tonnes	The North Sea Tonnes	The Baltic Sea Tonnes
Denmark				
Streams included waste water	25.000	4.000	950	54
Waste water, direct outlet	1.200	370	290	90
Industry	1.700	20	850	1
Denmart total	27.900	4.400	2.090	145
Other countries, approx.	1.180.000	370.000	104.000	36.000
From this Elben + Weser	(270.000)	–	(15.900)	–
Precipation a.o. (estimated)	3-600.000	4-500.000	8-9.000	4-5.000
Total	1.5-1.800.000	8-900.000	115.000	40.000

Table 5.7 **Annual mean input of nutrients for the 1980s to the North Sea and the Skagerrak, and to the Baltic Sea.**

Nutrients to the internal waters from other marine areas

The Baltic Sea retains and converts a large part of the added nutritive substances as mentioned in section 3.4.2. The amount flowing out to the Danish open waters is difficult to calculate. For nitrogen, the quantity in normal years is estimated to be in the range of 100-130,000 tons per year (Wulff et al. 1990), but only a smaller part is, as inorganic nitrogen, available for the production of algae and, moreover, the major part of this has always existed. For phosphorus the amount flowing out in a normal years is estimated to be about 5,000 tons per year.

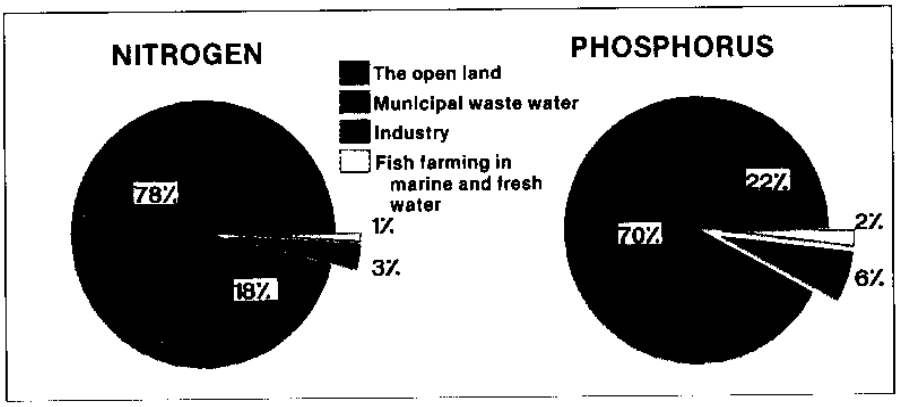

Figure 5.18

Distribution of discharge and runoff of nutrients to the internal waters from Denmark in the years 1981-88.

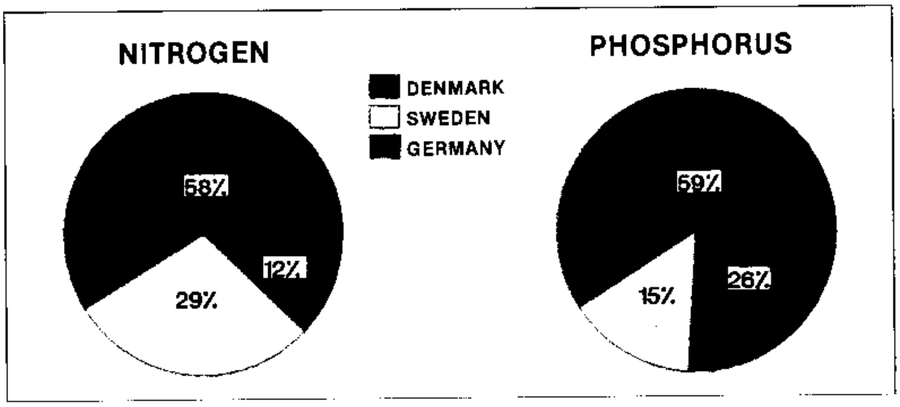

Figure 5.19

Distribution of discharge and runoff of nutrients to the internal waters from Denmark, Sweden and Germany in the years 1981-88.

Since the 1950s, the outflow of phosphorus has increased, and after the 1960s, a smaller increase has been seen in the outflow of nitrogen. During the 1980s, the outflow seems, however, to have stabilized on a new level. In 1989, the outflow of nitrogen was close to the minimum of this level, if not lower.

In connection with the inputs to the North Sea, the input to the German Bight, from the Elbe, the Weser and the Ems, is of special interest, in so far as part of the runoff from those areas affects the conditions along the Jutland North Sea coast and at times, with the »Jutland current«, can contribute to the input of nutrients to the internal Danish waters. In 1989, this situation occurred, and it is estimated that 13-17,000 tons inorganic nitrogen above the normal flowed in which is estimated to be much more than the average for such inflows (Ærtebjerg et al. 1990).

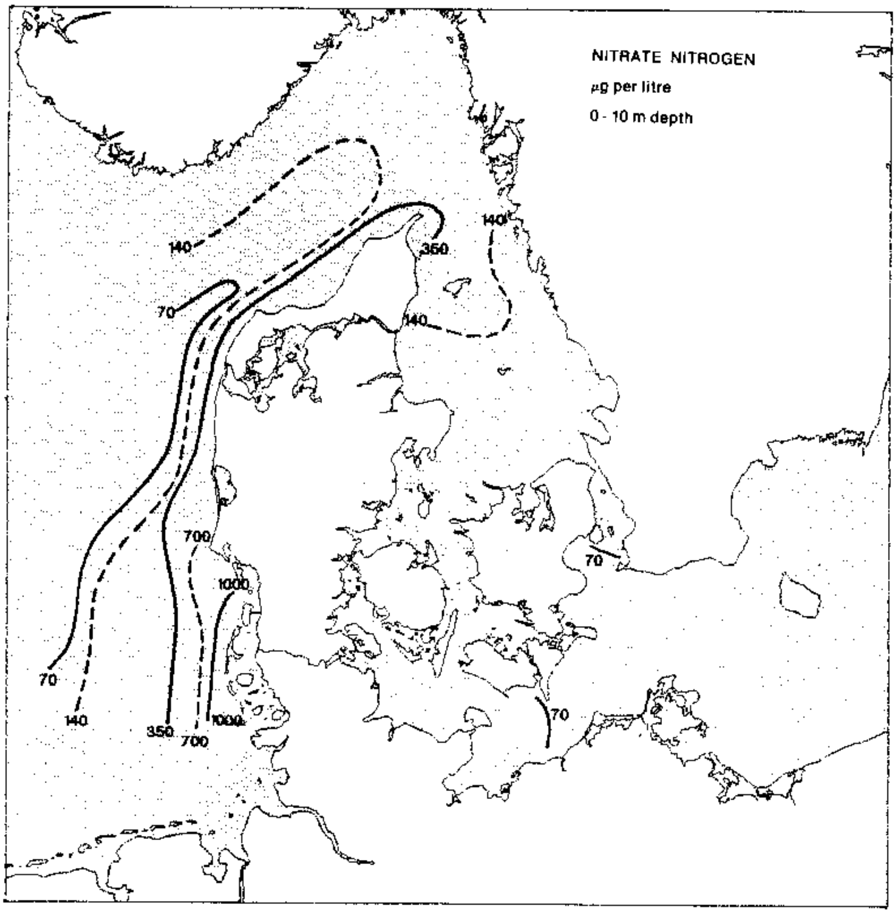

Figure 5.20

Concentration of nitrate along the west coast of Jutland and in the Kattegat in February 1989. (According to Ærtebjerg et al. 1990).

Annual variations in input of nutrients from land

It varies how much of the added nutrients from the various coastal waters reaches the open waters. The coastal waters, and especially the closed inlets, can like the Baltic Sea retain and decompose the nutrients. However, this usually takes place in the summer period, wherefore the major part of the nitrogen runoff during the winter months reaches the open waters where it has the most important effect.

The input of nitrogen during the summer period is of decisive importance to the state of the coastal waters. During the period May to

September 1989, the contribution of the Danish point sources as a whole was a little below 60% of the input. The variation is big, ranging from some few percent in areas with relatively small loads to more than 90% in strongly loaded areas.

5.4.2. Nutrients in open marine areas

In the open parts of the internal waters, the winter concentration of inorganic nitrogen (nitrate, nitrite and ammonia) has shown to have a decisive importance for the algae production in the following summer. Throughout the period 1980-1989, the winter contribution has been highest in the Belt Sea and southern Kattegat and lower in the Skagerrak and in the areas of the Kattegat where the water is most frequently mixed up with water from the Skagerrak. The lowest concentrations – about half as high as in the Belt Sea – have been found in the Baltic Sea area, i.e. south and east of the bottom thresholds between the Belt Sea and the Baltic Sea.

During the period 1975-1989, there has been a general increase in the nitrate concentration, largest in the Belt Sea and the southern Kattegat and lowest at Arkona in the Baltic sea and the southern part of the Øresund. During the second part of the 1970s, a fall took place, and the most important increase took place at the beginning of the 1980s, whereafter the level has generally been high without further development. The increase follows the same pattern as the development which has taken place in the runoff of nitrogen from the Danish land areas, which marked itself from the end of the 1970s and the beginning of the 1980s (Ærtebjerg et al. 1990 and Kristensen et al. 1990b).

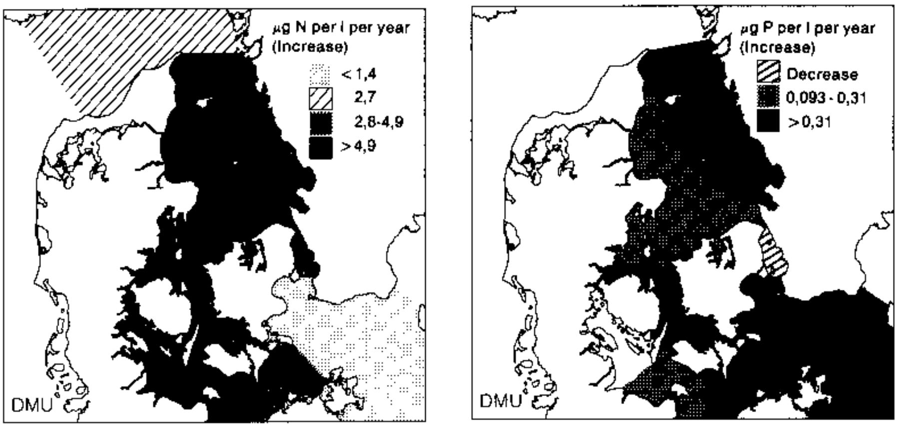

Figure 5.21 **The annual increase of winter concentration of nitrate and phosphate in the surface layer during the period 1975-1989** (Ærtebjerg et al. 1990).

The development in the concentration of phosphorus also shows an increase during the period 1974-1989, although the picture is not as clear as in the case of nitrogen. The increase is largest in the Belt Sea, but most clear in the areas which have the closest contact with the adjacent waters, the Baltic Sea and the Skagerrak. The Øresund area shows a fall which may be an expression of a reduced local input from waste water and industries (especially from Sweden). In spite of this, the primary production of plant plankton in the Øresund shows an increase concurrently with the increase in the nitrogen concentration.

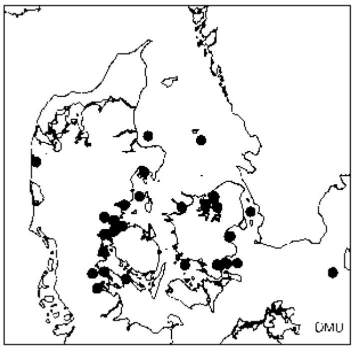

Figure 5.22
Mass occurrence of plankton algae in Danish marine waters in 1989.

5.4.3. Extreme growth of algae

Heavy growth of algae is especially in the spring period a common phenomenon in Danish open waters. The frequency and distribution of mass occurrences of algae, however, seem during the 1980s to have increased also at other times of the year, and with greater emphasis on certain types of algae, in some cases toxic. This has become an annual phenomenon in many inlets and bays.

The development in the growth of algae in 1989 did not differ from previous years. However, in 1989, there was no exceptional growth in the open waters, but only local blooming in inlets and bays. The reason is probably the lower input of nutrients in 1989 than in the 1980s as a whole. Figure 5.20 shows areas with mass occurrences during the year. Some of the algae are potentially toxic and as a consequence fishing of mussels was in periods prohibited in eastern inlets of Jutland and in the Little Belt.

5.4.4. Oxygen deficit, bottom animals and fish

There has always been, now and before, depletion of oxygen in exposed parts of Danish waters, but in most waters oxygen depletions in the 1980s have been more frequent, longer lasting and stronger than before. During the past nine years, the oxygen concentration in the bottom water has generally shown a fall, as seen for the northern Little Belt in figure 5.23. Oxygen depletions in the individual years

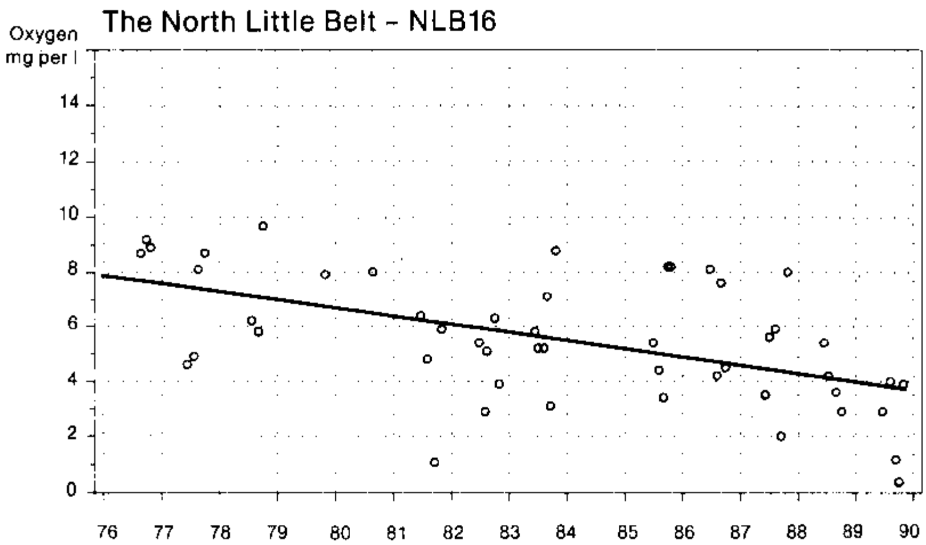

Figure 5.23

Development of the oxygen concentration in the bottom water of the northern Little Belt (Funen County 1990).

can be clearly related to the nutrient concentrations and the water transportation (Sehested-Hansen et al. 1990).

The biomass of bottom animals has fallen in the southern parts of the Kattegat and in other areas which have been significantly affected by critical oxygen conditions in the 1980s. Since 1981, fish mortality has been reported almost every year. The decrease in catch figures and stock of cod and plaice in the Kattegat and the Belt Sea seems to be connected to the increasing eutrophication and to more frequent depletions of oxygen, especially because the feeding basis is changed or disappears.

The first serious oxygen depletion with fish and bottom animal mortality in large areas even of the open waters, including the North Sea, and development of hydrogen sulphide in the southern Belt Sea, took place in September 1981 (National Agency of Environmental Protection 1984b). Since 1985, the stock of langoustine has been reduced in the Swedish part of the southern Kattegat, and in 1988 the last catchable stocks were almost exterminated.

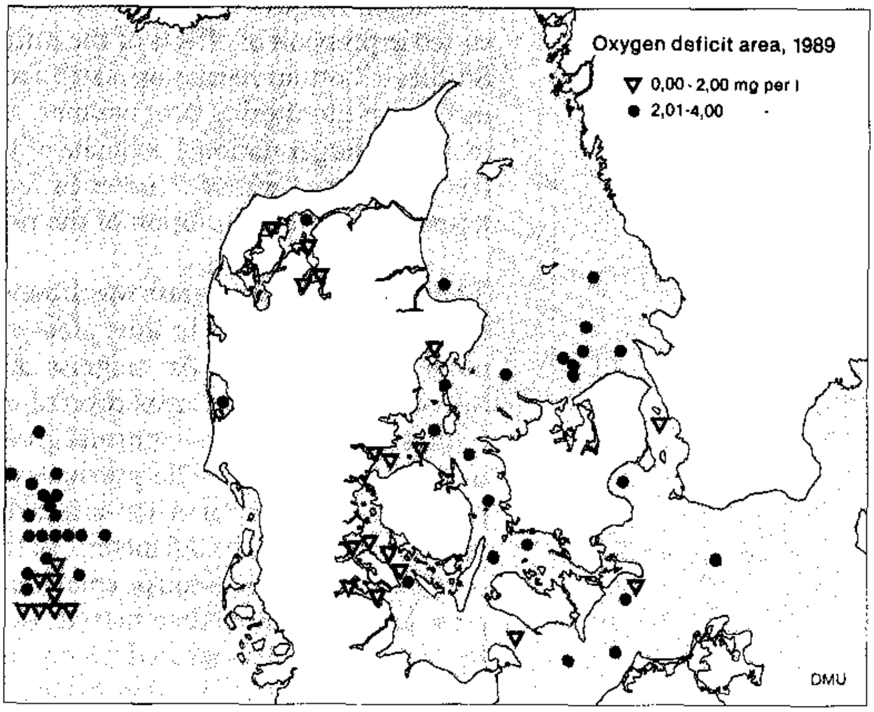

Figure 5.24 **Oxygen deficit in 1989** (Ærtebjerg et al. 1990).

In some water areas, as e.g. the deep soft bottom areas of the inlet Limfjorden and in the southern Little Belt, oxygen depletion and bottom animal mortality are natural phenomenon of older date. But even in these areas there is no doubt that the frequency and duration have increased and that larger areas than before are affected.

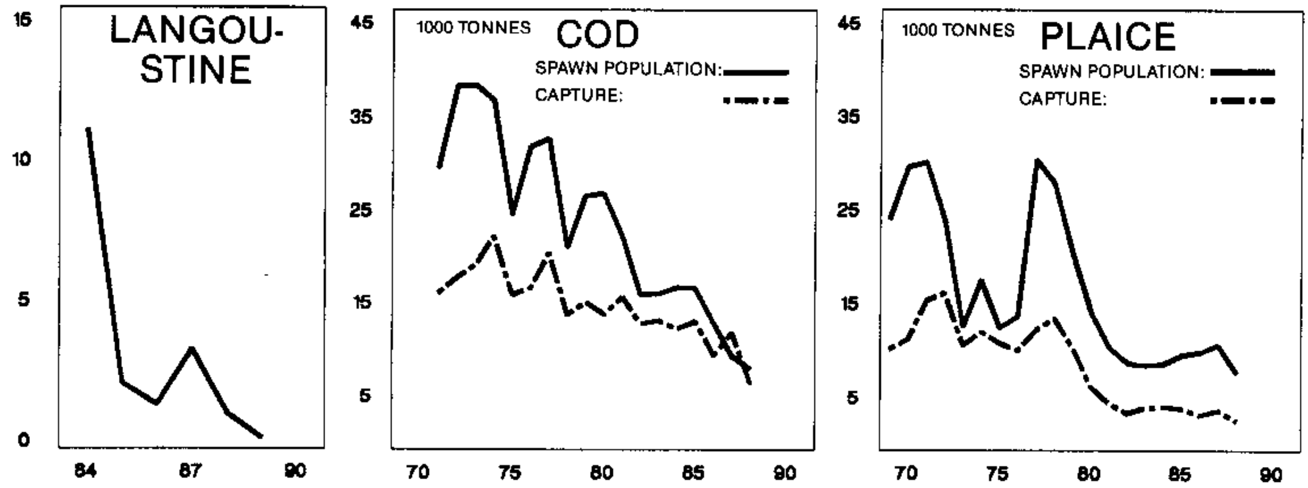

Figure 5.25 **Development in spawning stock and catch of cod and plaice, and standardized catch (CPUE) of langoustine in the Kattegat** (ICES 1989 and Baden et al. 1990).

5.4.5. **Distribution of eelgrass**

The depth range of eelgrass is, as mentioned in section 3.4.5, a well-suited expression of effects of the nutriousness of the coastal waters. Studies of bottom vegetation is still a relatively new activity as routine in Danish monitoring programmes, and, therefore, it is too early to make any larger national estimate of the development. For some inlets and coastal waters, studies in recent years, however, provide a foundation for a describtion of the present state.

The depth range of eelgrass was around the turn of the century usually down to 6-8 meters in inlet areas and down to 9-12 meters in the more open sea areas. An eelgrass disease 1932-1934 resulted in a heavy reduction of the areas covered by eelgrass, but from the 1960s, eelgrass has again been in normal growth and has been re-established in all coastal waters. The previous depth ranges are, however, not present today, not even in non-affected areas, where the highest depth range now seems to be 6-8 meters. In the major parts of the inlets, this possible depth limit is considerably reduced and areas covered by eelgrass have been more than halved. In some areas, bottom vegetation has completely disappeared, as e.g. in the inlet Ringkøbing Fjord, where in 1972 there was a dense stand of bottom vegetation and where today such is not found in depths of more than 80 cm. Figure 5.26 shows a picture of the decline of the eelgrass in the inlet Nissum Fjord since 1966.

In the inlets changes are observed of the vegetation in through the inlets with reduced number of strains, less cover degree and depth range and a higher dominance of annual algae. All signifying an increasing deterioration of the biological state in through the inlets.

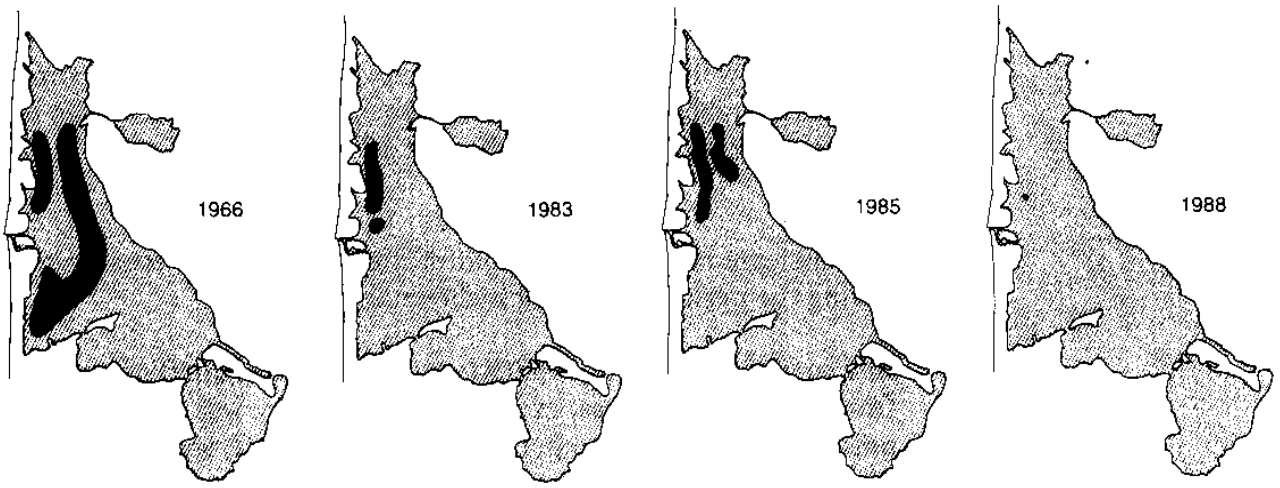

Figure 5.26 **Development of range of bottom vegetation in Nissum Fjord from 1966 to 1988** (Ringkøbing County 1990).

5.4.6. The cause of the eutrophication effects

The eutrophication effects in the Danish waters must be considered to be a result of the *changes* (i.e. the increases) which has taken place in the input of nutrients from the period before the effects occurred, and till now. Since the 1930s, the input of both nitrogen and phosphorus has increased. The input of nitrogen only rose slowly at the beginning of the period, most pronounced during the 1960s to the higher level in the 1980s, see section 5.2.5. The input of phosphorus also increased slowly in the beginning of the period, quickly during the 1960s, and has since the beginning of the 1970s been relatively constant.

In the coastal waters the effects have shown by a gradual deterioration of the state, in most cases with the largest deterioration during the 1970-1980s. In the open waters the effects have only appeared in the 1980s, i.e. after the strong increase in the input of nitrogen. For the internal Danish waters, the following have been established from the beginning of the 1970s to the 1980s:

- The atmospheric deposition of nitrogen has doubled. The largest increase occurred from the beginning of the 1960s to the end of the 1970s (Hovmand 1990 and Grundahl 1990).

- The runoff of nitrogen from Danish land areas increased by about 50%, more in the western areas than in east Denmark (Kristensen et al. 1990b).

- The input from waste water sources have been unchanged, but the preceding increase to the present level had its effect, first and foremost in the coastal waters.
- There has been a small increase in the input of both nitrogen and phosphorus from the Baltic Sea.
- The inflow from the »Jutland current« to the Kattegat give at times a considerable nitrogen contribution, which has probably also increased about 50% during the past 10-20 years.

The increase in the annual input of nitrogen to the internal waters during the period 1970-1989 is shown in table 5.8.

In a »normal year« in the 1980s (see table 5.6) the runoff of nitrogen from Danish land areas, excluding waste water, was about 70,000 tons per year. Of this input, the background runoff, without cultivation contribution, is about 15,000 tons per year, and the increase from the end of the 1970s is estimated to be 15-25,000 tons per year (Kristensen et al. 1990a). This increase in the runoff from the Danish land areas is responsible for 30-35% of the total increase. Besides, if the Danish contribution to the increase in the atmospheric deposition, 8-10,000 tons (Hovmann 1990) is included, Denmark itself is responsible for 40-50% of the total increase in the runoff of nitrogen to the internal Danish waters.

The increase of runoff of nitrogen from the Danish land areas since the end of the 1970s corresponds to 20-35% of the present total mean runoff from Denmark to the internal waters (table 5.6). The increase on account of the contribution from cultivated areas is 40-50% of the part of the runoff, exceeding the background runoff.

Increase for:	Tonnes per year
Atmosphere deposition	15 - 20.000
Runoff from the Danish countryside	15 - 25.000
Runoff from other countries	
Sweden and Germany	10 - 14.000
Input from the Baltic Sea	3 - 5.000
The Jutland current (From time to time)	5 - 10.000
Total (rounded off)	50 - 70.000

Table 5.8 **Increases in input of nitrogen to the internal waters in the period 1970 – 1989.**

The discharge of waste water in 1970-89, about 20,000 tons nitrogen per year from Denmark, and at least the same from Sweden and Germany, is in the same range as the increase in the input of nitrogen from the Danish land areas.

5.4.7. Fulfilment of quality objectives

Compared with the general objectives of an unaffected or only slightly affected flora and fauna, the state of Danish open water areas is considerably deteriorated in many parts. In the coastal waters this shows i.e. in a decline of the rooted bottom vegetation, more frequent and larger range of special types of algae – sometimes toxic, change and impoverishment of the fauna and a decline in fishing.

In the open waters, the deteriorations show first and foremost in a larger production of algae – here also with more frequent occurrences of special types of algae, but most important by larger and more widespread oxygen depletion and resulting changes in the fauna of the bottom and consequences for the fishing of certain species of fish. The important deteriorations have to different degrees taken place during the past 20-30 years. First in the closed inlets and, in the 1980s, in the open waters too.

Summing up, there is no doubt that an increase has taken place in the average nitrogen concentration in the internal Danish waters. The increase rate is largest in the Belt Sea and the southern Kattegat and smallest in areas where mixing takes place with water bodies coming from the outside.

Fulfilment of the general objectives

The general objective are not fulfilled in most of the near-shore waters, along the southern part of the west coast of Jutland and in the southern part of the Kattegat, and not at all in the more closed bays and inlets. The objective is besides threatened or strongly threatened in large parts of the more open waters, such as the sea surrounding the small southern islands, the Great Belt, the southern Belt Sea, the Arkona Basin (in the Baltic Sea), the Øresund, the northern Kattegat and the western North Sea. In figure 5.27, it is shown to which degree the general objectives have been fulfilled for the marine areas, and where it is estimated that the fulfilment of the objective is most threatened.

The main reason for the deteriorations can be ascribed to an increased input of nutrients, first and foremost nitrogen and in part phosphorus. This increase has taken place gradually since the 1930s, but primarily within the past 20-30 years. For the internal waters, the inputs from the adjacent land areas i.e. from Denmark, Sweden and Germany, have been of decisive importance, whereas the present remote transportation from the North Sea, and to a lesser degree from the Baltic Sea, may play a role at times. The major part of the important input of nutrients comes from Denmark which can also be held responsible for about half of the increase which during the past 10-20 years has resulted in the most important deteriorations of the environ-

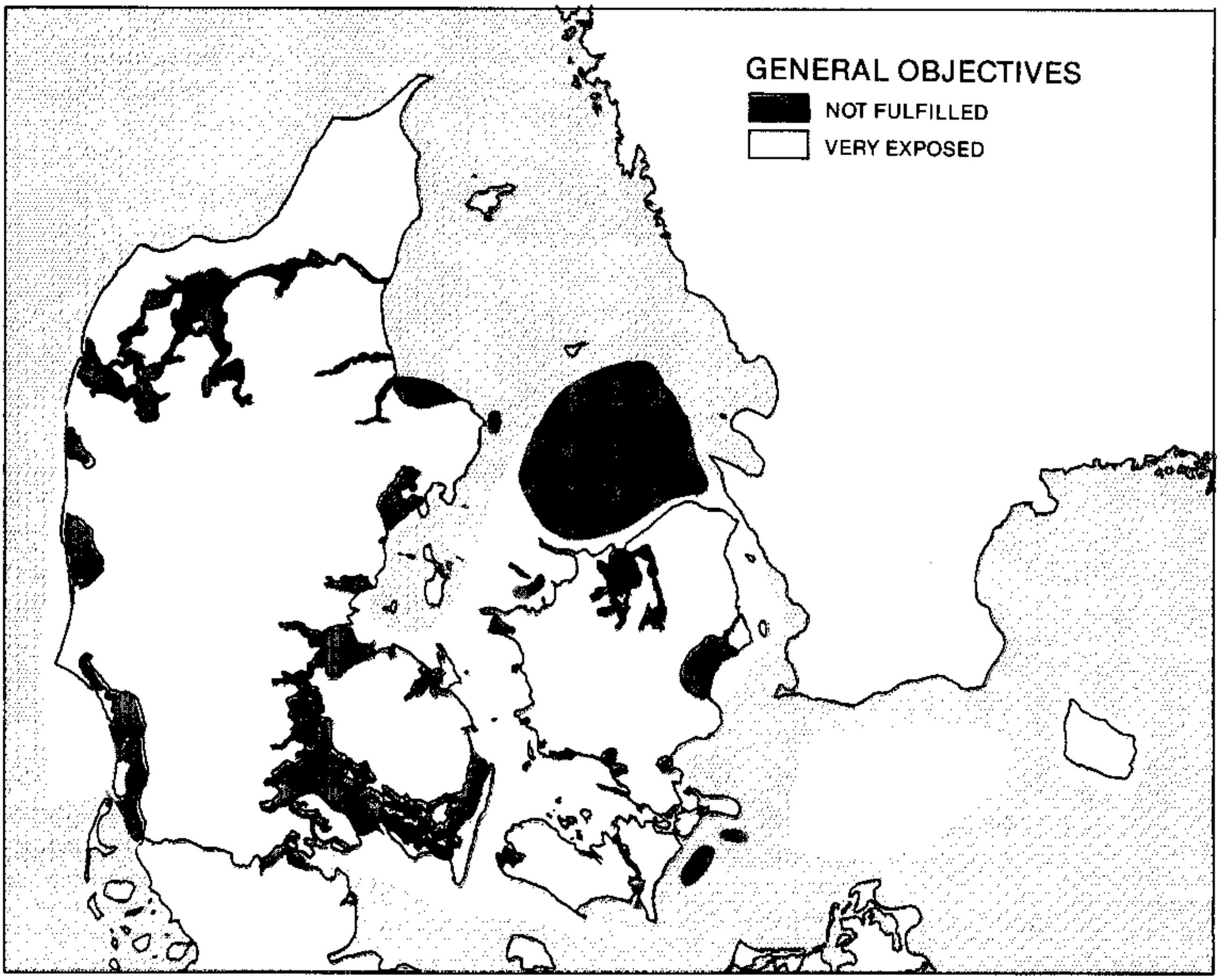

Figure 5.27 **The state in relation to the general objectives for the environmental quality in the Danish waters.**

mental state. The total increase has its main emphasis on the runoff from land areas and the atmospheric contribution. The input from point sources has not increased considerably within the period, but the total contribution from these sources is of the same order as the increases mentioned.

Possibilities for improvements

It is still difficult to predict precisely how large improvements in the open waters will bee seen as a result of a reduced input of nutrients.

The effects of the implemented measures are only now beginning to show and the measures of the Action Plan for the Aquatic Environment are only to be fully carried out during the next few years. To this comes that nature, after the implementation of the measures, will need a reaction time. The first improvements must, however, be expected in the coastal waters, but the extent and course of time will depend on how big damage has to be corrected.

The effect of a reduced nitrogen input was indicated in 1989. The input to the internal Danish waters was in this year considerably lower than in mean for the 1980s, as a result of much lower precipitation and runoff compared to normal years. The effect first of all showed in some coastal waters as e.g. the inlet Limfjorden, where an improvement for the bottom vegetation was seen.

Besides, for the open internal waters model calculations show that a 50% reduction of the nitrogen runoff to these waters – from both Denmark, Sweden and Germany, will improve the oxygen conditions in the bottom water so that oxygen depletion will occur less frequently. However, oxygen depletion under special critical conditions as in 1981 will not be avoided. Certainty against such occurrences presupposes that the contribution from the atmosphere and the input from the Skagerrak/«Jutland current« is reduced too (Sehested-Hansen et al. 1990).

6. Economy of the Action Plan for the Aquatic Environment

Below is given information on how big *investments* have been or will be carried out as a consequence of the requirements outlined in the Action Plan for the Aquatic Environment, and on how large *extra* annual operating expenses these new investments will result in when fully implemented.

All amounts in the following have been calculated in 1989-prices and without value added tax.

6.1. **Agriculture**

Agricultural *investments* in increased storage capacity, according to the requirements of the Plan, is difficult to calculate and the following figures are therefore subject to great uncertainty.

On the basis of some examinations made, as previously mentioned, it can be estimated that about 75% of all animal husbandries at the end of 1989 fulfilled the requirements of storage capacity.

Total investments in storage capacity during the period 1985-89 can be estimated to have been about 2 billion Danish kroner. Of the remaining husbandries, it is expected that about half of them will invest in increased storage capacity up to the end of 1992, and that total investments in these three years will amount to about 1 billion Danish kroner.

Totally, investments in agriculture during the period 1985-92 are thus *about DKK 3 billion.*

In connection with the above, it should first of all be pointed out that the investments in the first three years of this period were not based on the Action Plan for the Aquatic Environment, but on the previous NPO Action Plan, and secondly that this figure comprises all investments and thereby also investments carried out without requirements made by the environmental authorities.

Investments in storage capacity is entitled to subsidies and it can be estimated that for the entire period a total amount of more than DKK 1 billion will be paid to agriculture by way of public subsidies.

The investments made in storage capacity will provide an opportunity to utilize animal manure better, which is the purpose of the investments. The corresponding reduction in the consumption of commercial fertilizers will give savings, which in part will offset the increased operating costs and interest and depreciation linked to the storage plants.

6.2. Municipal waste water treatment

In 1989 the National Agency of Environmental Protection, in collaboration with the Water Treatment Council and all involved municipalities, completed a nationwide development plan, including time sequences, for the municipal treatment plants in accordance with the requirements of the Action Plan for the Aquatic Environment.

The development plan comprises *investments* for the entire period 1987-95 of about DKK 7,5 billion. To this shall be added investments which are not included in the plan, partly in a number of localities dominated by fishing industry, partly in plants where the extent of investments has not yet been determined. These investments are estimated to add up to DKK 300 million.

It is thus expected that total investments in municipal waste water treatment will amount to about *DKK 8 billion* during the period 1987-95. Of this amount it can be estimated that about two-thirds, or DKK 5 billion, may be referred to the requirements outlined in the Action Plan for the Aquatic Environment itself.

The increase of annual *operating costs,* as a result of the investments in treatment plants in the period 1987-95, may be calculated to about DKK 380 million. That this constitutes a considerable increase can be seen from the fact that average annual operating costs in the period 1977-86 were about DKK 550 million. That is to say that annual operating costs after 1995 will be about 70% higher than the average for 1977-86.

6.3. Treatment of industrial waste water

The 19 large industries with own separate treatment and discharge of waste water, comprised by the requirements of the Action Plan for the Aquatic Environment, are expected to have to *invest* a total of *about DKK 1 billion* in improved waste water treatment.

It can be estimated that these investments, when fully implemented, will result in extra annual *operating costs* of about DKK 100 million.

7. Summary

Recent research and monitoring results have decisively improved the basis for evaluations of the importance of nutrients for the aquatic environment. Much better knowledge has been obtained about cause and effect and about the present state and development.

7.1. Sources of nutrients emissions

Agriculture is the dominating source of the nitrogen emission. In the summer when the runoff is low, the emissions of nitrogen from waste water treatment plants may, however, become of considerable importance in certain situations.

On the other hand, it is the waste water discharges which dominates the phosphorus load. In water areas with low waste water emission, the agricultural emission of phosphorus may, however, be important locally.

7.1.1. Emissions from agriculture

The nitrogen loss from agriculture has been estimated. It is found that leaching from fields must have been about 230,000 tons N per year before the implementation of the Action Plan for the Aquatic Environment. Further, the waste water from dung heaps, etc. are estimated to have been about 20,000 tons N per year. It is emphasized that the leaching figures are very uncertain, and it is pointed out that the leaching shows considerable variations from one year to another and between the different parts of the country.

Leaching from a field varies strongly with type of crop, type of soil, climate and the former cultivation of the field. Establishment of catch-crops and green fallowing may limit leaching. It is estimated that changes of crops in recent years, including establishment of catch-crops, have resulted in a reduction in the average annual leaching of about 15,500 tons N. It is furthermore estimated that straw ploughing has reduced the annual leaching by about 3,000 tons N.

A clear relationship has been found between the increase of total input of fertilizers and the increase in leaching. It is found that animal manure distributed in the spring has the largest fertilization effect, whereas distribution in the autumn may result in considerable leaching. Moreover, it has been found that part of the farms use fertilizing practices which result in unnecessary losses. An efficient utilization of animal manure and a careful planning of the fertilization are thus decisive in order to reduce leaching. It is estimated that the average annual leaching within the past few years has been reduced by about 11,500 tons N as a result of improved handling of manure, slurry and fertilizers.

The decrease in arable land is estimated to have resulted in a reduction in annual leaching of 5,000 tons N. Finally, the emission of »waste water from farms« is now reduced by 15,000 tons to 5,000 tons N per year, which must be considered to be the lowest possible level obtainable in practice.

Thus, totally, the annual leaching is estimated to have been reduced by about 50,000 tons N, corresponding to about 20% of agriculture's total nitrogen discharge to the aquatic environment in the middle of the 1980s. This means that leaching in 1990 may be estimated to have been just under 200,000 tons N. The target of the Action Plan for the Aquatic Environment is a reduction of 50%.

By marginalization of agricultural land to permanent grass or natural areas, it has been demonstrated that a considerable reduction of leaching is obtained very quickly. It has also been found that reestablishment of wetlands can probably lead to removal of considerable amounts of nitrogen. Such initiatives have not, however, been taken into use to any large extent so far.

The phosphorus discharge from agriculture is relatively small compared with the amounts of fertilizer used. However, phosphorus concentrations in drainage water correspond to the critical limit for reaching a satisfactory environmental state in lakes.

Ammonia volatilization from agriculture

Ammonia volatilization by application of animal manure is, before the implementation of the NPO Action Plan and the Action Plan for the Aquatic Environment, estimated to about 50,000 tons N per year. To this comes a loss from stables and storage plants. It is estimated to be about 35,000 tons N per year, including loss from animals on grass. Finally a loss of about 10,000 tons N per year occur in connection with ammonia lixivition. Total ammonia volatilization from agriculture was thus 95,000 tons N per year.

It is estimated that the requirements of the Action Plan for the Aquatic Environment of ploughing in of animal manure has reduced the ammonia volatilization by about 20,000 tons N per year.

Nitrogen input from the atmosphere

Part of the ammonia volatilization is transformed and re-deposited as ammonium over the sea areas and elsewhere. It is estimated that about half of the atmospheric ammonia contribution to the Kattegat originates from Denmark. The rest comes mainly from Germany, whereas Eastern Europe contributes a very small part only.

7.1.2. Discharges from towns

Based on new measurements, the discharge of the treatment plants, before the implementation of the Action Plan for the Aquatic Environment, are now estimated to have been 20,000 tons N per year and 6,000 tons P per year.

In accordance with the county recipient quality plans and the Action Plan for the Aquatic Environment, expansions are presently carried out in the waste water treatment plants, which within the next few years is expected to reduce the nitrogen and phosphorus discharges by 67% and 80%, respectively. The goal of the Action Plan for the Aquatic Environment is 60% and 72%, respectively.

For 1989, the discharges from rainwater outlets are estimated to 800 tons N per year and 200 tons P per year. The discharge of waste water from single properties is estimated to 3,000 tons N per year and 1,000 tons P per year. These figures, however, are subject to some uncertainty.

No reductions will,in connection with the Action Plan for the Aquatic Environment, be achieved for these relatively small contributions. But when the other waste water contributions have been reduced, these discharges will have an increased weight in the load of the aquatic environment.

7.1.3. Discharges from industry

The major part of the discharges from industry is led to municipal treatment plants. For the separate discharges, before the implementation of the Action Plan for the Aquatic Environment, it is estimated that to lakes, watercourses and coastal waters, discharges were made of 4,300 tons N per year, 3,200 tons P per year and 114,000 tons COD per year. In addition, 900 tons N per year and 250 tons P per year were applied to arable soils.

It is expected that the nitrogen and phosphorus discharges from industry will be reduced by 63% and 95% respectively. The goals of the Action Plan for the Aquatic Environment are 60% and 82%, respectively.

Accordingly, the objectives of the Action Plan for the Aquatic Environment for reduction in the nitrogen discharges will be fulfilled. The reduction in phosphorus discharges will be larger than the objectives of the Plan.

7.2. Effects of nutrients on the aquatic environment

The increase in discharges of nitrogen and phosphorus in the past decades has resulted in increased difficulties in maintaining a satisfactory drinking water quality. Increased growth of algae has been found in both freshwater and marine water areas, with adverse changes in the natural ecological balance, and inthe worst cases oxygen depletion and fish mortality, as result.

7.2.1. **Ground water**

Due to percolation of nitrate contaminated agricultural water, it is estimated that two-thirds of the ground water recharge in the upper reservoirs today have a content of nitrate which is often twice the maximum limit of 50 mg nitrate per liter laid down in the EEC Drinking Water Directive.

A considerable removal of nitrate in the deeper strata limits, however, the nitrate penetration under natural conditions. But sometimes the nitrate removal results in acidification and increased content of sulphate. Abstraction from deep reservoirs may in certain cases draw down contaminated water and result in nitrate pollution even at great depths.

The quality of the drinking water in Denmark is largely satisfactory today, but there are problems with too large content of nitrate in many single water supplies (wells). In most regions, it is at present possible to avoid nitrate problems by abstracting from deeper ground water sources. But, other problems may arise instead as a result of poor water quality due to salt intrusion, increased humus content etc. In an area from Djursland to the Limfjord, the nitrate pollution is a serious constaint for the water supply, and it must be expected, that with unchanged nitrate load, it may be difficult to obtain sufficient drinking water of satisfactory quality within the next 10-20 years.

In general the present trends in the nitrate content of ground water imply that the water works in certain regions will have increasing problems of abstracting drinking water of satisfactory quality from existing wells. A restructuring of the water supplies may therefore become necessary in the years to come.

7.2.2. **Watercourses**

No relationship has been established between input of nutrients and the biological condition in the streams, except in case of very high nutrients levels. Discharge of organic matter with waste water is the most important factor. Also, the maintenance of the streams and the physical structure of the watercourse are of great importance.

Only about one third of the streams fulfil the objectives of the recipient quality plans.

In the 1970s, an increase was observed in the nitrogen transportation of the streams to the marine areas, whereas a stabilization has taken place in the 1980s at a level of about 110,000 tons N per year and 4,200 tons P per year.

7.2.3. Lakes

The state of the lakes is mainly determined by the phosphorus concentrations. Even in cases of relatively low concentrations, the growth of algae has increased and the visibility of the water is strongly reduced. As a result of this, further deteriorations in the plant and fish populations in the lakes will occur. The critical concentration is around 0.1 mg P per liter.

The quality of the lakes is generally poorer than the requirements laid down in the county regional plans, and during the past 10 years no noteworthy improvement has been observed in the condition of the lakes.

Only a reduction of phosphorus contributions from the open land, including the sparsely built-up areas, can make the water of Danish lakes clear and thus ensure a versatile fauna and flora.

7.2.4. Near-shore waters

In near-shore waters, conditions are determined by a complicated interaction between input of nitrogen and phosphorus, depending on local conditions.

It has been found that the objectives for the quality of coastal waters have only been met in a few cases. An increasing number of cases have been found of excessive growth of filamentous algae (algal bloom of brown algae), depletion of eelgrass areas, oxygen depletion and fish mortality. The most drastic effects have been found in the near-shore areas and it is also here that the largest effects of a reduction in the nutrients load must be expected.

In connection with the low precipitation and runoff in 1989, a clear, but probably temporary, improvement of the state in several near-shore waters was seen. This indicates that a permanent reduction of loads will relatively quickly lead to an improvement of the deteriorated conditions.

7.2.5. The open marine waters

It has been demonstrated that there has been an increase in extent as well as frequency of occurrences of oxygen depletion in the Danish marine waters in the 1980s. At the same time there has been a drastic decrease in the catch of plaice, cod and lobster which is most likely related to the deteriorating living conditions at the sea bottom.

Besides, it has been demonstrated that the increased occurrences of oxygen depletion in the 1980s in the Danish marine waters are closely linked to the increases in the input of nitrogen.

The Danish share of the increase in the input of nitrogen has been significant, whereas the share from the Baltic Sea have only been of minor importance.

It has been shown that a 50% reduction in the Danish (and Swedish) discharges of nitrogen will result in a clear improvement of oxygen conditions in the least critical years and that damage to the fauna will be reduced. On the other hand, an improvement in the most critical years will require that steps are also taken against the airborne input and against the contributions from Germany and the North Sea.

In the North Sea oxygen deficit occurs in connection with transport of nutrients with the »Jutland current«. Their origin is the European discharges into the Bight of Heligoland.

7.3. Conclusion

On the basis of the results of the research and monitoring programmes it can be established that:

- during the past 20-30 years, a serious deterioration has taken place of the state of the aquatic environment due to increased discharges of nutrients.

- The Danish discharges are the main factor for the deteriorations in ground water, lakes, inlets and near-shore waters. In the Kattegat and the other internal waters, the Danish emissions are a considerable factor too. A reduction of the Danish emissions will, therefore, be of decisive importance for all parts of the aquatic environment.

- Fulfilment of the objectives of the Action Plan for the Aquatic Environment will ensure clear improvements in ground water, in inlets and in the near-shore waters. Also in Kattegat and the other internal Danish waters a fulfilment of the objectives will result in improvements.

- The targets of reduction of the emissions from municipal treatment plants and industrial dischargers are expected to be reached. The discharges from agriculture has been reduced in recent years, and this development will continue with the further implementation of the measures of the Action Plan for the Aquatic Environment, but it cannot be expected that the targets for agricultural emissions will be reached by 1992 or later.

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In the past decades the Danish aquatic environment has been subject to a considerable increase in input of nutrients from agriculture, waste water and energy production. This has led to a deterioration in the quality of groundwater, a growth of algae in freshwater streams, lakes and marine environment, oxygen depletions and fish mortality. Status and trends of nutrient discharges are given, and the resulting impacts on groundwater, streams, lakes and marine environment are demonstrated.

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Resumè:
Vandmiljøet har i de sidste årtier været udsat for en betydelig stigning i belastningen med næringssalte. Resultatet har været forringelse af grundvandskvaliteten, forøget algevækst i ferske og marine vandområder samt iltsvind og fiskedød. På grundlag af de seneste forsknings- og overvågningsresultater vises udviklingen i belastningen af næringssalte fra landbrug, industri, trafik og byer. Endvidere belyses de deraf følgende miljøændringer, som er konstateret i grundvand, vandløb, søer og marine områder.

Emneord:
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