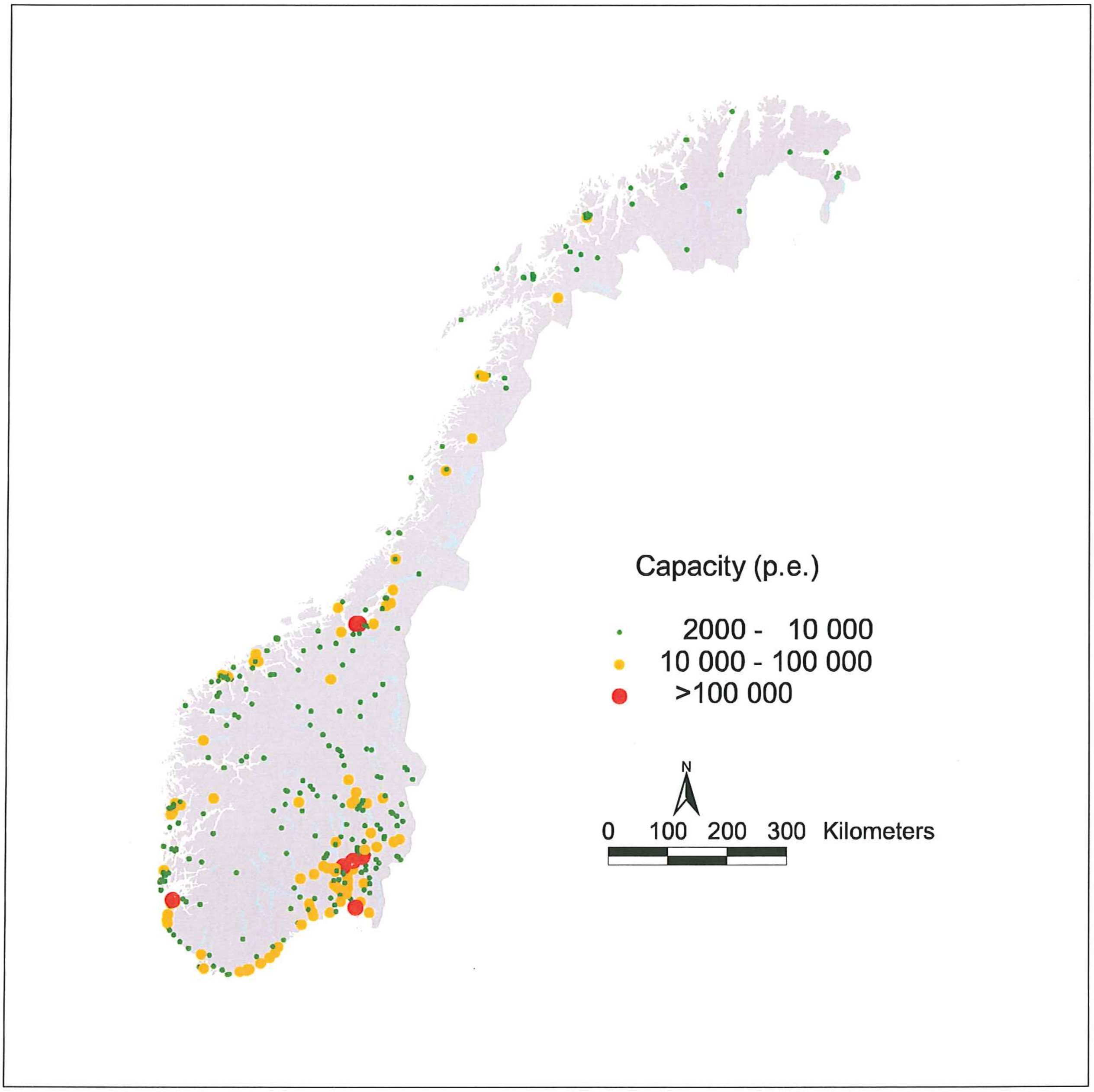
REPORT SNO 4466-2001

Implementation of the Urban Waste water Treatment Directive in Norway

An Evaluation of the Norwegian Approach regarding Wastewater Treatment



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REPORT

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Abstract

This report discusses the effects and benefits of full implementation of the Urban Waste Water Treatment Directive in Norway. The Norwegian policy for wastewater treatment has targeted phosphorus removal as the primary measure to reduce adverse effects of discharge of wastewater to freshwater and marine recipients. Chemical precipitation is therefore used at more than 70% of the wastewater treatment plants. This technique is very efficient in reducing the phosphorus concentration and in addition gives a high reduction of suspended solids, micropollutants and bacteria. The removal of organic matter is, however, not always sufficient to fulfil the requirements in the Directive. The high amount of available fresh water, and the high sensitivity of fresh water systems to incresed phosphorus loading implies that the primary load of organic matter from wastewater is less important than the organic matter produced in the surface waters on the basis of nutrients from the wastewater (secondary organic load). For wastewater dicharged to marine waters the situation is more diverse due to the large variation in receiving water conditions. The most sensitive marine recipients are the fjords with restricted exchange of deep water. Like in lakes, the secondary organic load caused by primary production may contribute far more than the primary load to the oxygen depletion of the deep water. Therefore nutrient removal is required as the primary measure also for wastewater discharged to marine waters.

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1. Kommunalt avløpsvann	1. Urban Wastewater
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Preface

In 2001, the Norwegian Pollution Authority commissioned the Norwegian Institute for Water Research (NIVA) to perform an evaluation of the environmental benefits of implementation of the Urban Waste Water Treatment Directive in Norway. The section in this report on the history of wastewater treatment in Norway has been compiled by Svein Stene Johansen, The sections on the evaluation of effects of wastewater on freshwater recipients and the description of water quality status in lakes and rivers have been made by Dag Berge, Torulv Tjomsland and Torsten Källqvist. A similar analysis of the marine environment has been made by Jarle Molvær and Eivind Oug.

Oslo, 10.5.2002

Torsten Källqvist
Project leader

Contents

Summary

The wastewater treatment policy in Norway has been tailored to meet local and regional environmental quality objectives. Due to the large quantity of runoff and scattered population, only 0.7 % of the available freshwater resources are utilised as municipal or industrial water supply, and the load of wastewater into receiving waters is generally very low. This means that the oxygen demand resulting from degradation of the organic matter from urban wastewater is low, compared with the oxygen pool in the receiving waters. Consequently, oxygen depletion in rivers due to discharges of urban wastewater has not been a problem in Norwegian freshwaters to date. Eutrophication, on the other hand, represents a significant problem in many watercourses, and particularly in lakes. In these systems, phosphorus is the primary limiting element for production of algae. The organic biomass that can be produced from the content of phosphorus in wastewater may be fifteen times higher than the amount of organic matter in the wastewater. The oxygen demand caused by this secondary organic load is mainly expressed in the deep layers of lakes, which are the most vulnerable environments in terms of oxygen depletion.

Since eutrophication and the secondary organic load arising from this process, have been identified as more crucial for the water quality than the organic load from urban wastewater, the treatment technology in Norway has mainly been focused on phosphorus removal. The phosphorus removal is performed by installation of chemical precipitation at treatment plants serving about 60 % of the population. In the most nutrient sensitive areas, where additional nitrogen removal is required, the chemical treatment is combined with biological treatment. A recent survey of plants with mechanical/chemical treatment showed average removals of approximately 60% for BOD_5 and COD. The average effluent concentration of organic matter, measured as $BOD_{5,}$ was 38 mg/l. There were, however, large variations between the plants and it was estimated that about 38% of the plants fulfil the requirement for BOD removal in the Directive. On the other hand, the P-removal at chemical treatment plants normally exceeds 90%, which is well above the Directive's requirement for effluents to sensitive areas (>80 % removal).

During the last twenty years, environmental monitoring has demonstrated that the policy to focus on P-removal has been successful in rivers and lakes severely affected by pollution from urban wastewater before the implementation of modern treatment. A reduction in the density of plankton algae and increased transparency of the surface waters have been observed in lakes where urban wastewater represents a significant part of the P-load. The removal of organic matter that is achieved by the chemical treatment is sufficient to avoid significant heterotrophic growth in the rivers and streams where urban wastewater is discharged.

The treatment of wastewater discharged into coastal waters is adapted to the local recipient conditions, as well as to the need for regional reductions of pollutant loading. In some fjords where the bottom topography prevents continuous exchange of the deep water, periodic oxygen depletion may occur even without any anthropogenic input of pollutants. Organic matter from wastewater or from stimulated algal production has the effect of increasing the extension in time and space of anoxic water masses under the said conditions. Like in lakes, the secondary organic load arising from production of algae greatly exceeds the primary load from urban wastewater. Therefore, removal of nutrients has been the primary measure to reduce algal growth in the surface layers of marine recipients and to reduce oxygen problems in deeper layers of these recipients. The role of phosphorus and nitrogen as limiting factors for primary production in marine waters may vary in time and space, but P-removal is considered as an effective measure to reduce local eutrophication.

Based on a scientific evaluation, we see no need for a change in the Norwegian recipient-orientated strategy for the purpose of complying with the Urban Waste Water Treatment Directive. A number of recipient studies are in the final phase (such as those dealing with the main outfalls of wastewater to nutrient sensitive area in the outer Oslofjord - and the Trondheimsfjord) or are being planned (such as the new Arendal outfall to coastal waters and the four outfalls to the fjord area around Bergen). The Mandal outfall of wastewater (mechanical treatment) to the sensitive area is being considered for upgrading to chemical precipitation. The outfalls with no treatment or fairly coarse mechanical treatment in northern Norway are also under consideration for upgrading.

A further evaluation of the need for upgrading the treatment of these and other wastewater outfalls should be performed whenever deemed appropriate. Based in the above mentioned issues, we reccomend to pursue the current policy in Norway on wastewater treatment as it, in our opinion, complies with the design for monitoring and reporting in the Council Directive concerning urban wastewater treatment.

1. Background

The policy for abatement of pollution from urban wastewater in Norway is not fully in line with the EU Urban Water Treatment Directive (91/271/EEC). The Norwegian policy is tailored to meet local environmental quality objectives, and the treatment methods are adjusted to the specific receiving water conditions in Norway. This has led to less focus on removal of organic matter, measured as biochemical oxygen demand (BOD), in favour of removal of inorganic plant nutrients, primarily phosphorus (P).

The full implementation of the Urban Waste Water Treatment Directive in Norway would require reconstruction of treatment plants that are primary designed for P-removal, to achieve a more efficient removal of organic matter.

The optimal wastewater treatment in Norway may be different from that of countries in central and southern Europe because of factors such as different:

- Geology
- Climate
- Hydrology and receiving water conditions
- Population density and distribution

This report describes the current Norwegian policy on wastewater treatment in view of the factors mentioned above. Furthermore, it summarises the history of wastewater treatment in Norway and experiences of the implementation of this policy. The environmental improvement that can be achieved by full implementation of the Urban Water Treatment Directive is assessed.

2. Population density and distribution

Table 1 shows some key facts of importance for the utilisation of water resources in Norway. The average population density is low, and most of the population is located inland in the southeastern part of the country and along the coast. The distribution of the population is indicated in figure 1. An increasing portion of the population is living in densely populated areas, defined as areas where more than 200 persons live and the buildings are located not more than 50 m from each other. Currently, approximately 75% of the Norwegian population are living in such areas. Despite this fact, there are still only a few large towns in Norway. Only 15 cities have between 20 000 and 100 000 inhabitants and only four have more than 100 000 inhabitants. All these four are located along the coast, with wastewater discharges to the sea.

Table 1. Key figures for Norway related to wastewater management policy.

Land area	km^2	323 810*
Population	people	4 503 000
Population density	persons/km^2	14
Coast line	km	21 192
Renewable fresh water	m^3	400x10^9
Renewable fresh water/person	m^3	88 830

*Spitsbergen excluded

Figure 1. Population centres with more than 5000 inhabitants (From Statistics Norway 2000. Based on map from *Statens kartverk*, permission number LKS 82003-596).

3. Environment and water resources

3.1 Geology, climate and hydrology

The predominant geological environment, especially in the most densely populated southern Norway, is highly resistant to chemical weathering. It is granite bedrock only partially covered by generally thin glacial deposits of similar mineralogy. The natural quality of surface water in this area is soft and acidic, with low concentrations of nutrients.

The annual precipitation is generally high (national mean of 1380 mm, with more than 1000 mm in half of the country). Because of the low evapotranspiration, the mean runoff is as high as 1145 mm. Consequently the available freshwater resources are plentiful, on average almost 90000 m^3/person. The degree of utilisation of these resources for industrial and domestic purposes is less than one percent, which is among the lowest in the world, as shown in **Figure 2**.

Temperature is another climatic factor with implications for the treatment of wastewater and effects of organic pollution. The generally cold climate in Norway (e.g. as compared to central Europe), is reflected by a low temperature of the wastewater as it reaches the treatment plants. A low temperature is disadvantageous for biological treatment processes and may reduce the efficiency of biological treatment of wastewater.

Low temperatures in the receiving waters for wastewater effluents will have the effect to reduce the immediate effects of organic pollution. Because of the low temperatures, the oxygen saturation value in the receiving water is higher. Furthermore, the degradation of the organic matter is slow, which means that the oxygen demand is delayed.

Due to the effect of glaciation, the Norwegian landscape is characterised by a large number of deep lakes. There area about 2500 lakes with surface areas exceeding 1 km^2. In addition there are 208 000 smaller lakes (0.01-1 km^2). (EEA 2001).

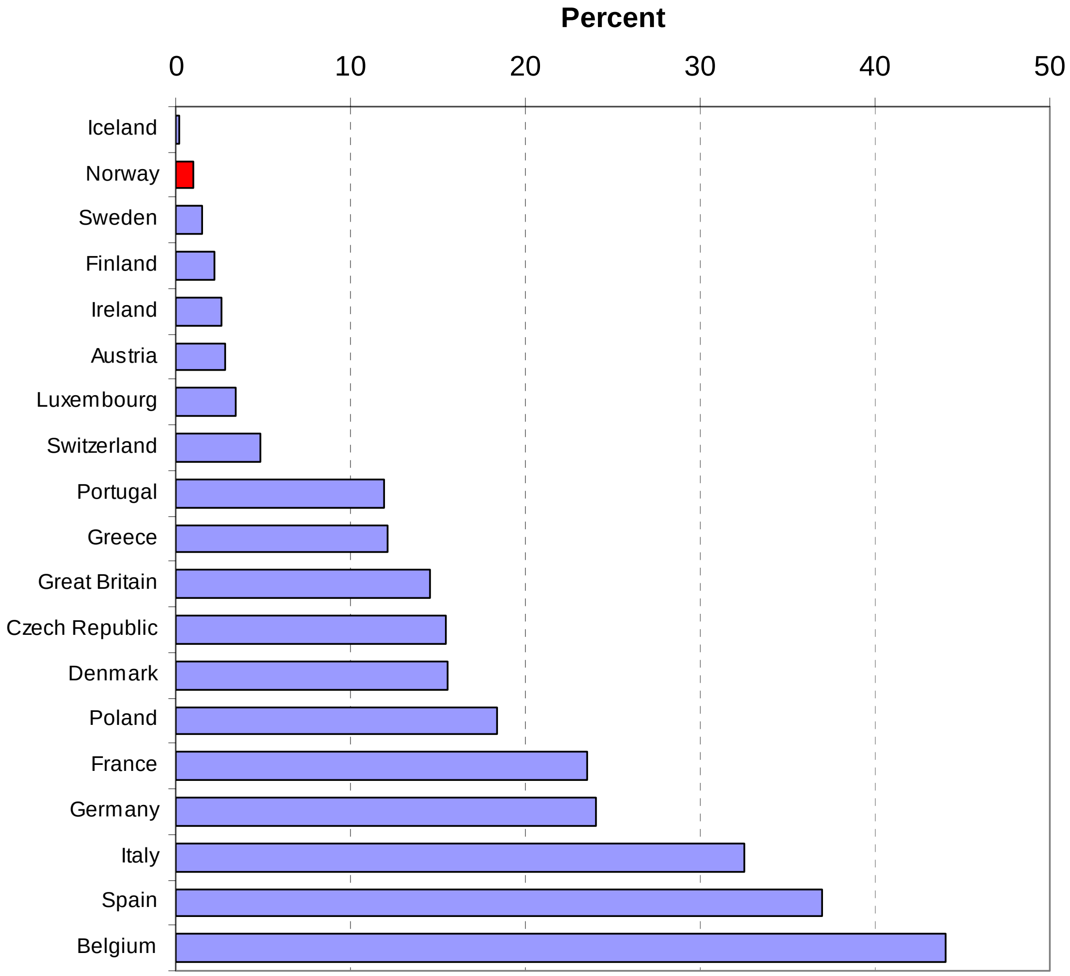


Figure 2. Fraction of total available freshwater resources utilised in some European countries. (Statistics Norway 2000).

3.2 Coastal zone

The coastal zone of Norway has an extremely varied topography and spans a range of habitats and ecosystems from very sheltered fjords to fully open and exposed headlands. The most characteristic features are the fjords, which may reach up to 200 km into the mainland, and the archipelagos and skerries, which in many regions form a broad intermediate zone between the mainland and the open sea. A typical fjord has a deep fjord basin (up to 1300 m) and a shallow threshold at the fjord entrance. The archipelagos are characterised by a mixture of shallow and deep sounds, channels and basins. With few exceptions the offshore waters are deep (> 200 m) close to the shore all along the coast.

The coastal waters along the Norwegian North Sea coast are basically a mixture of two water masses: Atlantic water (salinity>35) and freshwater. Most of the Atlantic water enters the North Sea through the passages between the Faroe Islands and Scotland and between the Faroe Island and Norway. Most of the freshwater comes from three sources, namely from local runoff to the coast, the Baltic Sea and the large rivers draining to the southern part of the North Sea. These water masses combine to form the Norwegian Coastal Current (NCC). (See **Figure 3**).

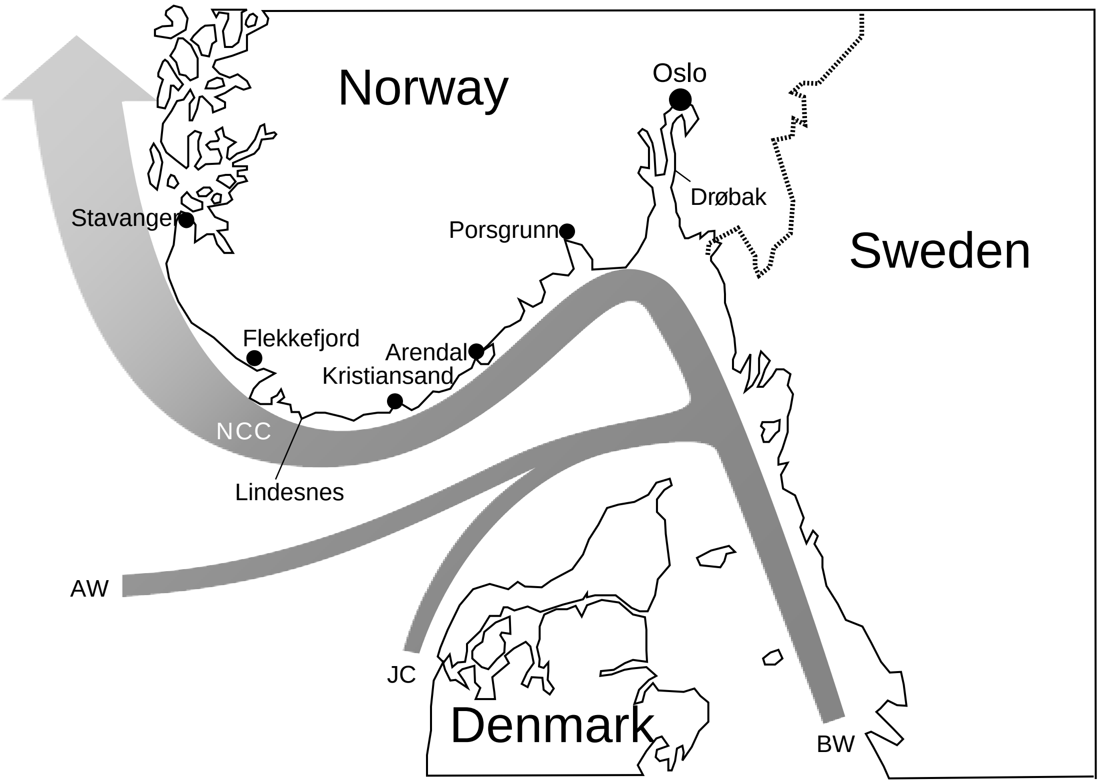


Figure 3. Dominating current pattern in the coastal area of southern Norway. (AW: Atlantic Water, BW: Baltic Water, JC: Jutland Current, NCC: Norwegian Coastal Current. From Molvær et al. 1997).

The water volume transport increases from typically 0.2-0.3 million m^3/s at the Skagerrak coast (**Figure 4**) to 1 million m^3/s or more off the coast of west Norway.

The water exchange in the coastal zone is driven by input of fresh water, tidal currents and meteorological forces (wind stress and air pressure variations). In most areas, the exchange of surface and intermediate water masses is rapid and extensive, often the matter of a couple of days or weeks. The tidal amplitude increases from typically 0.1 m on the Skagerrak coast to 1 m in northern Norway. Combined with similar increasing meteorological forces, this leads generally to higher water exchange on the coast of western and northern Norway than on the Skagerrak coast.

The fjords with shallow sills in southern Norway are of particular concern with regard to the discharge of effluent waters. In most of these fjords, the water masses are salinity-stratified with brackish water on top and seawater in the deep basin. The deep water is stagnant for shorter or longer periods and is only exchanged with oxygen-rich coastal water at intervals varying from months to several years. At the end of stagnation periods the oxygen concentration in the deep water will be low, and in many cases hydrogen sulphide is formed. On the Skagerrak coast the oxygen consumption in the fjords has increased significantly since 1980. This is considered to be an effect of a regional nutrient enrichment in the coastal water mass in Skagerrak (ANON 1997).

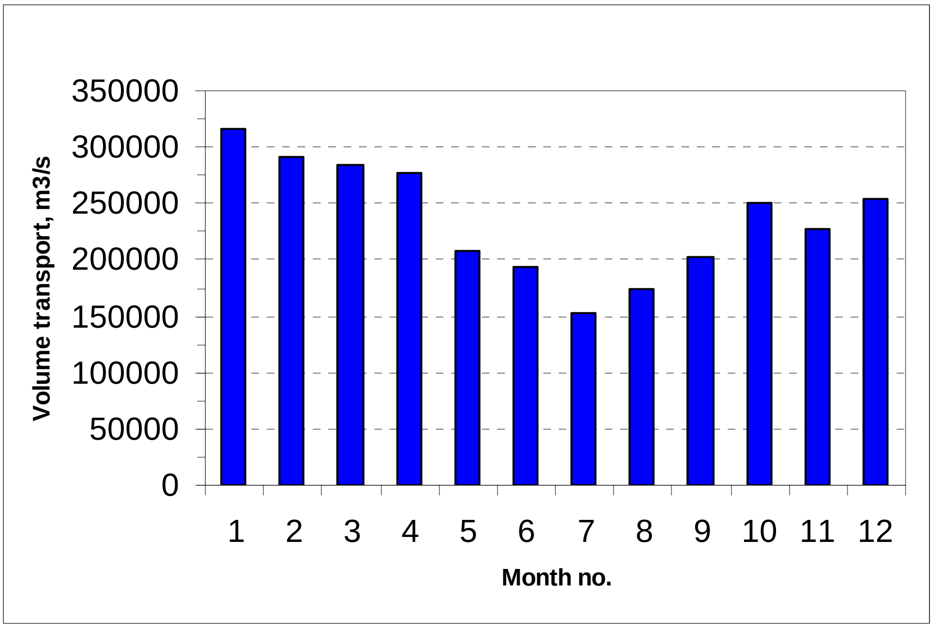


Figure 4. Calculated monthly average of water volume transport in the NCC off Arendal for the period 1988 - 95. (ANON, 1997).

Most of the population lives in topographically sheltered areas along the coast. Generally, the topography and the water exchange of the local recipients vary considerably, spanning from fjords with shallow sills and stagnant bottom water to bays and inlets with free exchange of water. Consequently, the sensitivity of the receiving waters to loading of nutrients and organic matter varies depending on the local conditions. Fjords, with more or less stagnant deep water are particularly sensitive to organic loading, which accelerates the oxygen depletion in the deep waters. Coastal areas with less restricted water exchange are less sensitive to discharges of organic matter and nutrients. The needs for reduction of the organic loads must, however, also be considered from a regional perspective.

4. Eutrophication status

4.1 Freshwater

In a OECD co-operative research programme targetting the causes and consequences of lake eutrophication, phosphorus was identified as a key factor (Vollenweider 1968, 1976, OECD 1982). A classification system for tropic status of lakes based on a yearly average concentration of total phosphorus was proposed, see table 2 below.

Table 2. Phosphorus concentations and lake productivity level

P-concentration level	Lake productivity level
[P] < 10 µg P/l	Oligotrophic
10 µgP/l ≤ [P] < 20 µg P/l	Mesotrophic
[P] ≥ 20 µg P/l	Eutrophic

These concentration levels were used in the P-loading models (Vollenweider 1968, 1976) and served as basis for the calculation of the corresponding acceptable, questionable and critical P-loading levels.

In the 1970'ies, studies showed that several of Norway's large and important lakes had increasing eutrophication problems. Research efforts were initiated to assess their maximum acceptable P-loading. During this work, it became clear that the P-concentration limits set by the OECD-group were not appropriate for calculating critical P-loads in Norwegian lakes. All large Norwegian lakes with a P-concentration of above10 µgP/l had serious problems with respect to algal growth and blooms of cyanobacteria. The limit for acceptable lake P-concentration therefore had to be lower than 10 µgP/l.

The first empirical attempt to establish limits for acceptable P-concentrations in large Norwegian lakes was made by Rognerud et al 1979 and Berge et al 1980. Their recommendation was that the P-concentration in large lakes should be kept below 7 µgP/l. The natural background concentrations in this type of lakes are from 3-5 µg P/l. Most large lakes in Norway still have P-concentrations well below 7 µg P/l. The same sensitivity to phosphorus also seems to apply to the Norwegian clear-water streams and rivers. On this basis, the Norwegian Pollution Control Authority (SFT 1997) adopted the following water quality classes with regard to phosphorus concentrations in freshwaters (average summer concentrations):

Table 3. P-concentrations and water quality classes

P-concentration (µgP/l)	Water Quality Classes
< 7	I: Very good
7-11	II: Good
11-20	III: Fair
20-50	IV: Bad
> 50	V: Very bad

The scientific reason for which the Norwegian lakes seem to be more sensitive with regard to P-concentrations than the lakes in e.g. Central Europe is believed to partly be caused by the fact that Norwegian lakes:

1. are mostly deep, with sharp thermal stratification
2. have very low background nutrient content
3. have very low mineral content
4. have a long ice-covered period, and
5. their organisms are facing a short and intense growth season with light over most of the diurnal cycle.

The limits for acceptable P-concentration are less strict for shallow lakes (Berge 1987, 1990; SFT 1995). This applies, however, only to relatively few lakes in agricultural areas. The vast majority of Norwegian lakes are oligotrophic, deep lakes where 7 µg P/l should be regarded as upper limit for acceptable P-concentrations in the productive season.

Figure 5 shows the P-concentration in 1500 lakes scattered over Norway. It shows that the vast majority of lakes in Norway are oligotrophic. The eutrophic lakes are mainly small lakes situated in agricultural areas, or in densly populated areas. The nutrient poverty of the Norwegian lakes, compared to central European lakes, is shown in **Figure 6**.

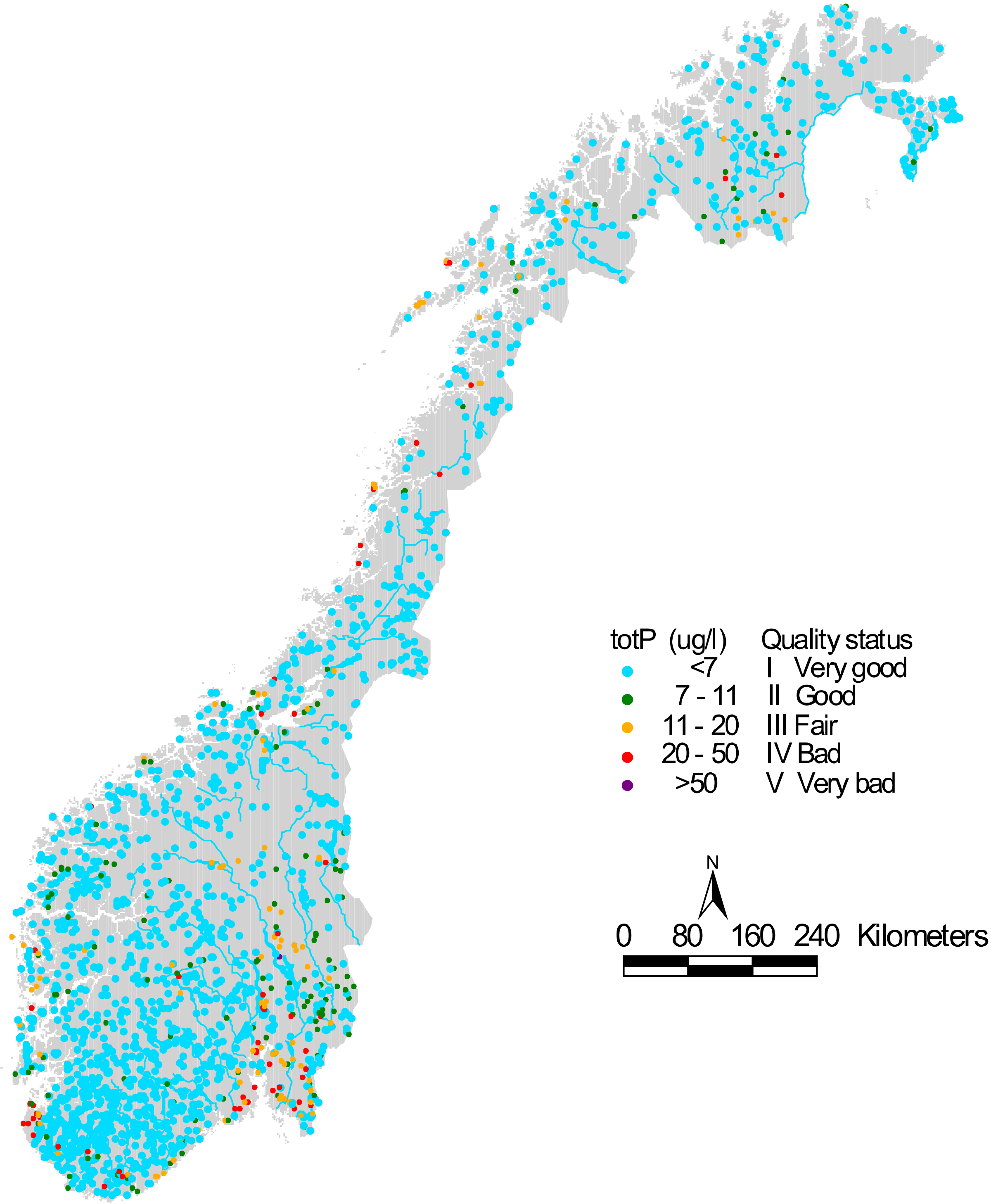


Figure 5. Distribution of lakes of different P-concentration in Norway. The colour scheme refers to the Norwegian classification of lake water quality based on total-P. (SFT 1997).

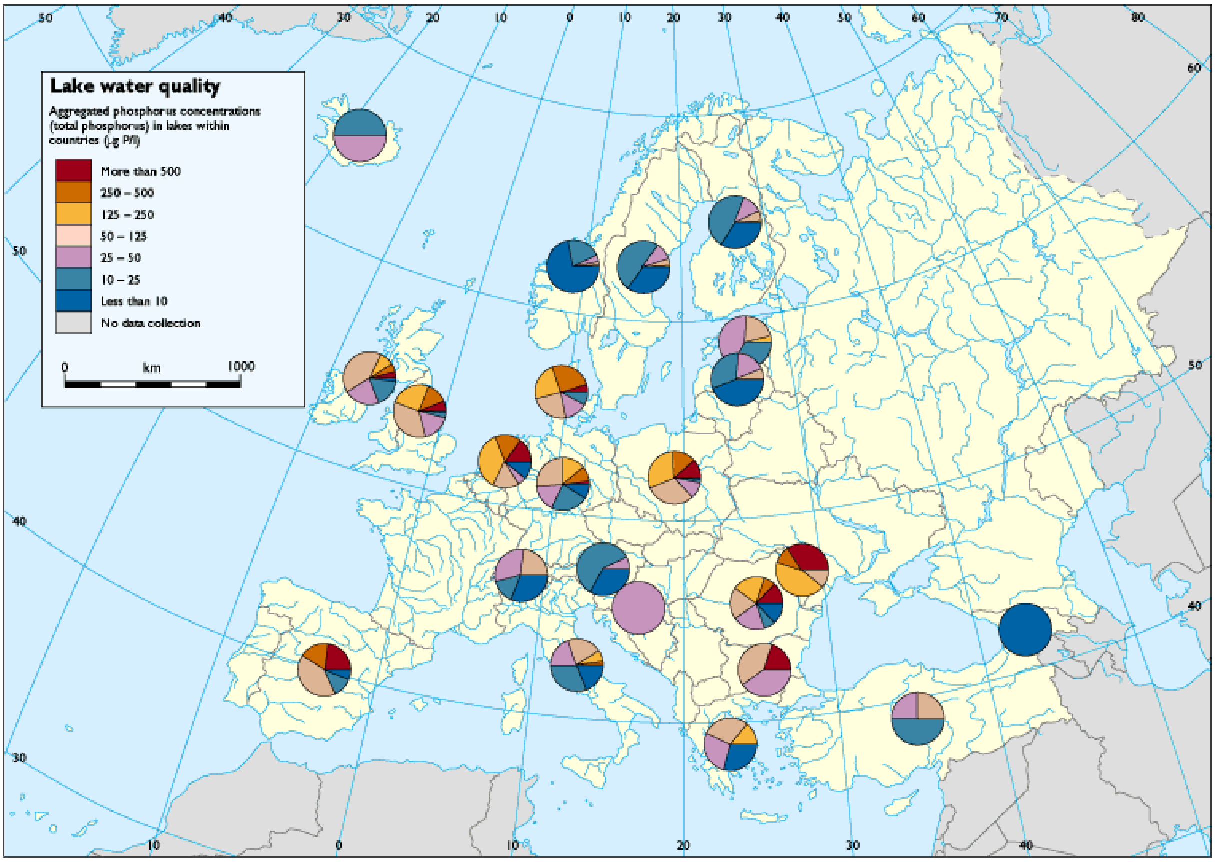


Figure 6. Water quality of lakes in European countries based on content of total phosphorus (EEA 2001).

4.2 Marine waters

The term 'eutrophication' has its origin in freshwater studies, but has been adopted to marine environments as well in the last couple of decades. In many coastal waters, the primary production has been stimulated by increased inputs of nutrients originating from human activites in bordering land areas. In cases of overloading, adverse effects may occur, such as excessive blooms of planktonic algae, increased oxygen consumption in bottom waters due to sedimentation and degradation of planktonic biomass, and kills of commercially important fish and shellfish species due to oxygen depletion. Eutrophication has also been associated with increased occurrences of harmful algal blooms. On a less dramatic scale, eutrophication will stimulate growth of benthic algae and bottom fauna, the latter through increased sedimentation of organic matter, produced in the surface waters.

The natural N/P ratio in seawater is lower than in fresh water, and normally in approximate balance with the requirements of the algae. On a general basis, nitrogen has been considered to be the limiting nutrient for primary production in the marine environment (Ryther and Dunstan 1971). More recently, more complex views have been published (see Sakshaug et al., 1983, Paasche and Erga, 1988, Larsson, 1988). The N/P-loading ratio in coastal areas may be influenced by local input from rivers and wastewater discharges. In the southern part of Oslofjord for example, phosphorus appears to be the primary limiting nutrient (ANON 1996). This varying balance between the nutrients prevents a general conclusion that nitrogen is the major regulation factor in the eutrophication of Norwegian coastal water and fjords.

The input of nutrients to coastal waters have several sources, such as :

- direct discharges from municipal and industrial wastewater
- agricultural runoff and runoff from drainage areas
- current transport with inflowing water masses
- atmospheric deposition from precipitation
- aquaculture

An extensive evaluation of the eutrophication in the Skagerrak has recently been completed (Forum Skagerrak 2001). In 1997, a similar evaluation of the coastal waters along Norwegian North Sea coast was published (ANON 1997). The following description relies heavily on these evaluations.

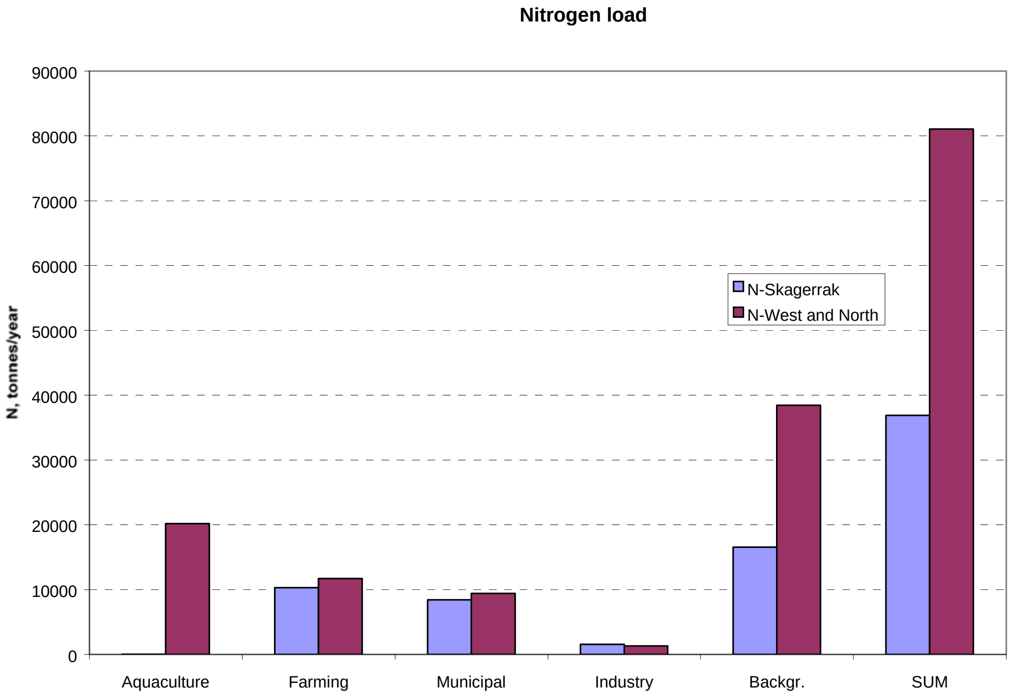
The Norwegian part of Skagerrak is downstream continental Europe (**Figure 3**). It is subjected to heavy inputs of current-transported nutrients from the southern North Sea and the Baltic (see ANON 1997). The significant nutrient contribution from Kattegat (an average of 160000 tons N, 8000 tons P per year) consists of nutrients from the Baltic Sea, nutrient loads from Germany, Denmark and and Sweden to the Belt Sea and the Kattegat and input from the atmosphere (**Table 4**). This load is far larger than the direct inputs from the bordering land areas of which the Norwegian sources contribute about 10-15% to the total. The inputs have increased significantly over the last decades, in particular for nitrogen. In the last ten-year period, there has been a decreasing trend in phosphorus load due to improved treatment of wastewater. For nitrogen, the trend is more uncertain as the land-based load varies according to the the variations in freshwater run-off (Forum Skagerrak 2001).

In Norwegian waters, the south-eastern region from the Swedish border to the county of Telemark is subjected to the highest input of nutrients from landbased sources. This is the most densely populated region of Norway (see **Figure 1),** as well as the coastal area into which some of the major Norwegian river systems flows into the sea. The inner Oslofjord is strongly affected by nutrient enrichment, whereas the outer part of the fjord and adjoining areas are more or less affected (Erga et al. 1990 and ANON 1996). Further south, along the Skagerrak coast and in western Norway, nutrient enrichment is generally restricted to enclosed fjords and basins (Erga et al. 1990 and ANON 1997). Fgures on the total Norwegian input of nutrients to the Skagerrak and to the waters of western Norway are updated on a yearly basis (**Figure 7**). They show that the background load has the highest contribution to the total inputs of nutrients on the Skagerrak coast. On the western and northern coast, the nutrient loads from aquaculture exceed those from municipal wastewater, and as regards phosphorus, even the background load.

Table 4. Calculated input of nitrogen and phosphorus in the 1990s for the upper 50 m of the water masses of Skagerrak. All figures in 1000 tons (Forum Skagerrak 2001).

Source	Tot-N	Tot-P	NO_3+NO_2
Direct from Denmark	2.7	0.16	
From Kattegat	162	8	
From Sweden	19.5	0.5	
From Norway	37.4	1.0	
From the atmosphere	36.6		
with the Jutland Current			160*
with Atlantic ocean water			440*
Total	258	9.7	600*

* only dissolved nutrients.



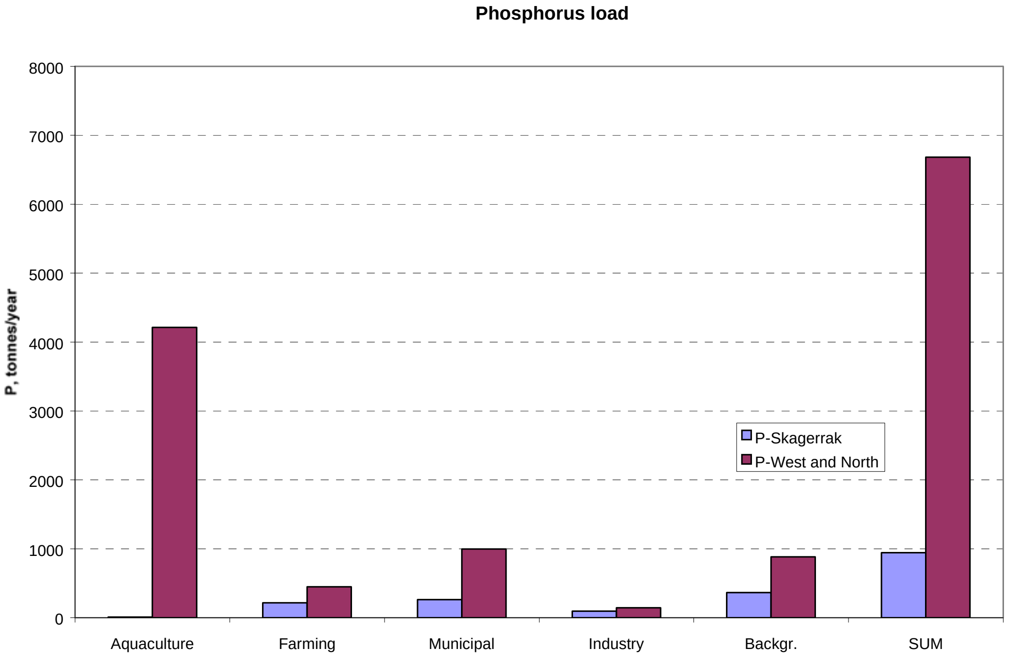


Figure 7. Nitrogen and phosphorus load from landbased sources to Skagerrak and the coast of west and northern Norway, as an average for 1998-1999. Based on data from (from Borgvang and Tjomsland, 2001).

In the outer Oslofjord and coastal Skagerrak waters, effects of this regional nutrient enrichment are shown as increased nutrient concentrations, with high N/P-ratios in spring and early summer. In the same area, there has been an increased occurrence and development of blooms of harmful algae. The oxygen concentrations during autumn in intermediate water layers have decreased with 0.4-0.8 ml O_2/l in the period 1970-95. There has also been an increase in the oxygen consumption and a decrease in the oxygen levels in sill basins along the coast. The increased consumption represents roughly an increase of the organic load of about 50% in the eastern Skagerrak and 20-30% in western Skagerrak. Long-term observations of oxygen conditions in the coastal waters of Skagerrak and in sill basins suggest that this increased oxygen consumption occurred during the first part of the 1980s and is mainly associated with the regional eutrophication of the area (Andersson 1996, Aure et al. 1996).

The local Norwegian nutrient load is mainly affecting the upper water layer in the northern part, and inshore areas in the eastern and western parts of the outer Oslofjord. There, the local load contributes significantly to the nutrient budgets and reduced water transparency. Stimulated phytoplankton production may have resulted in a doubling of plankton biomass and a 20% reduction of water transparency in this area. The increased plankton production is mostly transported out of the fjord and into the Norwegian Coastal Current, with little sedimentation into deeper water layers in the outer Oslofjord due to short residence time of the surface layer.

Further along the Skagerrak coast, the general policy regarding outfalls of municipal sewage has been to extend pipelines to areas of vigorous water exchange (Larvik, Risør, Arendal, Kristiansand, Mandal) or through deep water outfalls and trapping of the sewage plume so as to place the diluted wastewater in watermasses with free exchange with coastal water (Sandefjord, Langesund, Kragerø, Tvedestrand, Lillesand, Farsund, Flekkefjord).

The coastal waters are diluted by admixture of Atlantic waters on their way westwards along the southern coast of Norway. Due to the admixture, the concentration of nutrients and the N/P-ratio gradually decrease. They will reach 'normal values' in the region between Lista and Utsira (south-west of Stavanger) where the coastal current turns northwards (**Figure 3**). Algal blooms in Skagerrak are often transported by the coastal current past Lindesnes and north to Utsira, but seldom any further.

There are no indications that the coastal waters along the Norwegian west and north coast are affected by eutrophication. The local inputs of nutrients is relatively small and, with few exceptions, originate from small sources scattered over a large area. The fjords, in general, communicate openly with the waters of the Norwegian Coastal Current and there is extensive exchange of surface and intermediate water layers. The waters from the fjords mix with the Norwegian Coastal Current, which has a typical transport time along the western coast of 2-3 weeks. The local nutrient inputs to the western coast represent less than 1%, compared to the natural flux of nutrients in the Norwegian Coastal Current. However, as seen from Figure 7, aquaculture plants located in fjords and coastal areas represent a large – and increasing - source of phosphorus. The exceptions to the general situation are fjords with shallow sills, restricting the water exchange. In some areas these are notably overloaded by inputs of nutrients and organic matter.

5. Wastewater management in Norway - Historical account

30 years ago there were very few wastewater treatment plants in Norway, except the mechanical and biological plants in the City of Oslo.

The pollution load from urban wastewater has been reduced considerably since that time. One important reason for the rapid development within the wastewater sector was the establishment of a major research programme related to the transport and treatment of wastewater by the end of the 1960s. The research covered both the technological aspects of wastewater treatment and the biological effect of wastewater discharges in receiving waters. A research station was created outside Oslo and different treatment methods were tested in pilot- and full-scale plants with wastewater from a municipality near by. The effluents were discharged into several artificial river systems and the effects measured. The experimental design allowed direct comparison of the effect of different wastewater treatment techniques. It was found that the biological communities were more similar to the natural situation in channels receiving wastewater treated by chemical precipitation than in those with biologically treated wastewater.

Based on the experimental research, as well as studies of the natural receiving waters, it was realised that Norway could not directly adopt European policies and design criteria for wastewater treatment. Problems with heterotrophic growth and oxygen depletion were not predominant in the Norwegian rivers. The most important objective was to prevent excess algal growth in fjords, lakes and rivers**.** Reduction of phosphorous inputs and substantial investment in chemical treatment plants were the recommendations from the wastewater research programme. The research also lead to the development of several unique process concepts and optimisation related to the conditions in Norway.

The Ministry of Environment was created in 1972 and the Norwegian Pollution Control Authority (SFT) in 1974. SFT got the authority to issue municipal waste treatment and sewage directives to the County Departments of Environmental Affairs. The construction of wastewater treatment facilities was subsidised by the Government and new laws were introduced. In order to achieve an efficient reduction in the P-load also in separate wastewater discharges, a restriction on the concentration of phosphates in household detergents was introduced.

The latest trend has been to transfer more responsibility to the municipalities and counties to decide on their wastewater management policies, based on their local needs.

For marine waters, however, the Ministerial Declarations from the North Sea Conferences (1987 and 1990) on reductions in nutrient inputs to the North Sea have been leading for the actions in the Skagerrak area. According to these Declarations, the inputs from anthropogenic sources of nitrogen and phosphorus into areas where these are likely to cause pollution, directly or indirectly, should be reduced by the ordere of 50% of the inputs in 1985. SFT defined the coastal region from the Swedish border to the southernmost point of Norway (Lindesnes) to be a problem area with regard to eutrophication, in the sense of the declarations (see **Figure 8**). Directives to construct wastewater treatment plants with nitrogen removal were subsequently issued by the Norwegian government and the first plants became operational about 1995. The Declarations were later confirmed at the FourthNorth Sea conference in Esbjerg in 1995 and the Fifth North Sea Conference in Bergen 2002. At present, the Norwegian authorities require phosphorus removal to be installed in the problem area, whereas removal of nitrogen is only required for the eastern part of the Skagerrak coast. The delineation of the problem area is also considered to be in agreement with the specification in the EU Urban Wastewater Treatment Directive.

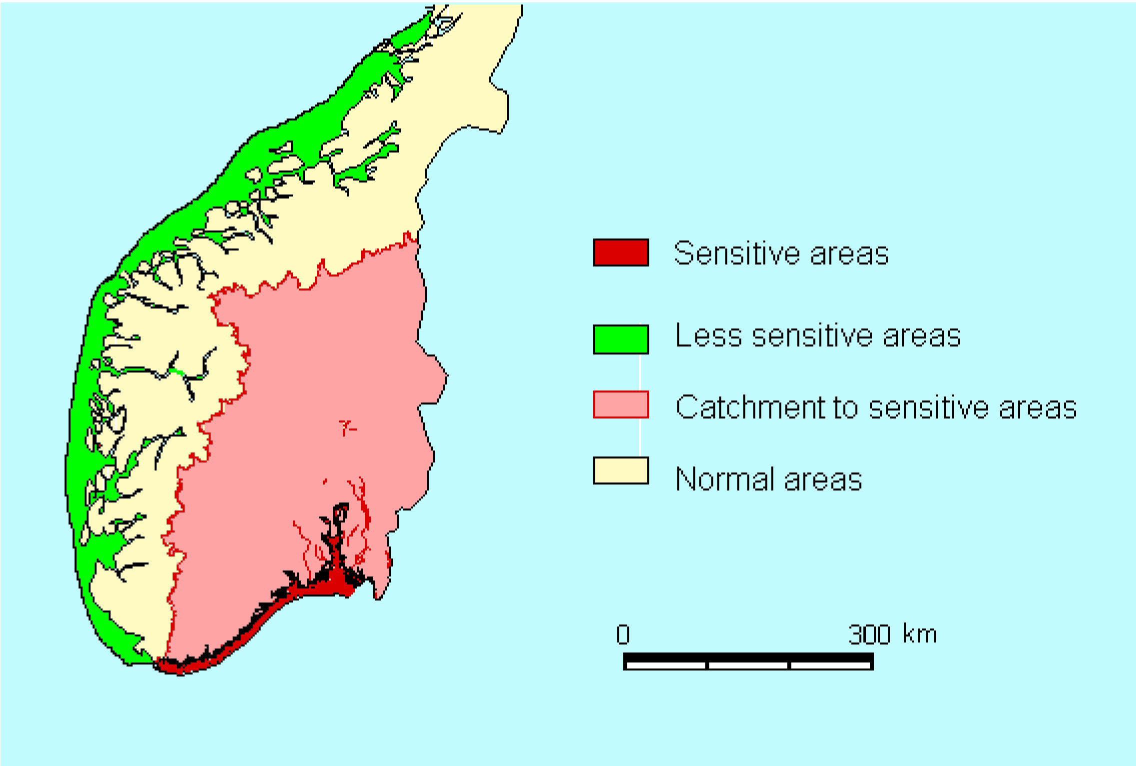


Figure 8. Areas in Norway defined as sensitive under the Urban Wastewater Treatment Directive

6. Development of wastewater facilities

Installation of wastewater treatment plants in Norway started around 1970 and was intensified in the late eighties. Today, 80% of the population is connected to municipal wastewater treatment plants. The remaining 20% have separate single treatment solutions and discharges. As a result of the research findings described in section 6, more than 60% of Norwegian wastewater undergoes chemical or chemical/biological treatment as shown in **Figure 9**.

The distribution and capacities of treatment plants are shown in **Figure 10** and the treatment processes applied at the treatment plants in **Figure 11**.

The wastewater sludge produced in 1996 amounted to 93 500 tons dry solids. Of this 58% was used in integrated plant nutrient management in agriculture and green areas. The rest was used in landscape landfills, temporally stored until a decision is made on final use, or is stored permanently on separate sludge fills.

The total length of the Norwegian sewer systems is about 35 000 km, covering 4.1 million people. This gives an average length of 8.2 km sewer per inhabitant. Combined sewers account for 31%, while 48% are wastewater and 21% storm water sewers. The figures reflect that the population is very scattered.

During the period 1976 to 1996, 3.4 billion euro were invested in the Norwegian wastewater sector, of which 18.5% were government grants. The overview of costs in the wastewater sector is presented in **Figure 12**.

The installation of wastewater treatment has considerably reduced the pollution from municipal wastewater during the last years. This can be exemplified by the estimated annual loads of P and N to the coastal zone of southern Norway (see **Figure 13).** The extensive use of chemical treatment has resulted in a more effective reduction of P than of N. The last five years, installation of biological treatment processes has been carried out several chemical treatment plants in order to fulfil the international agreements on nitrogen reduction. This has also resulted in a reduction of the load of organic matter from those treatment plants, which mainly discharge to the coastal area in southern Norway defined as a sensitive area under the Urban Waste Water Treatment Directive.

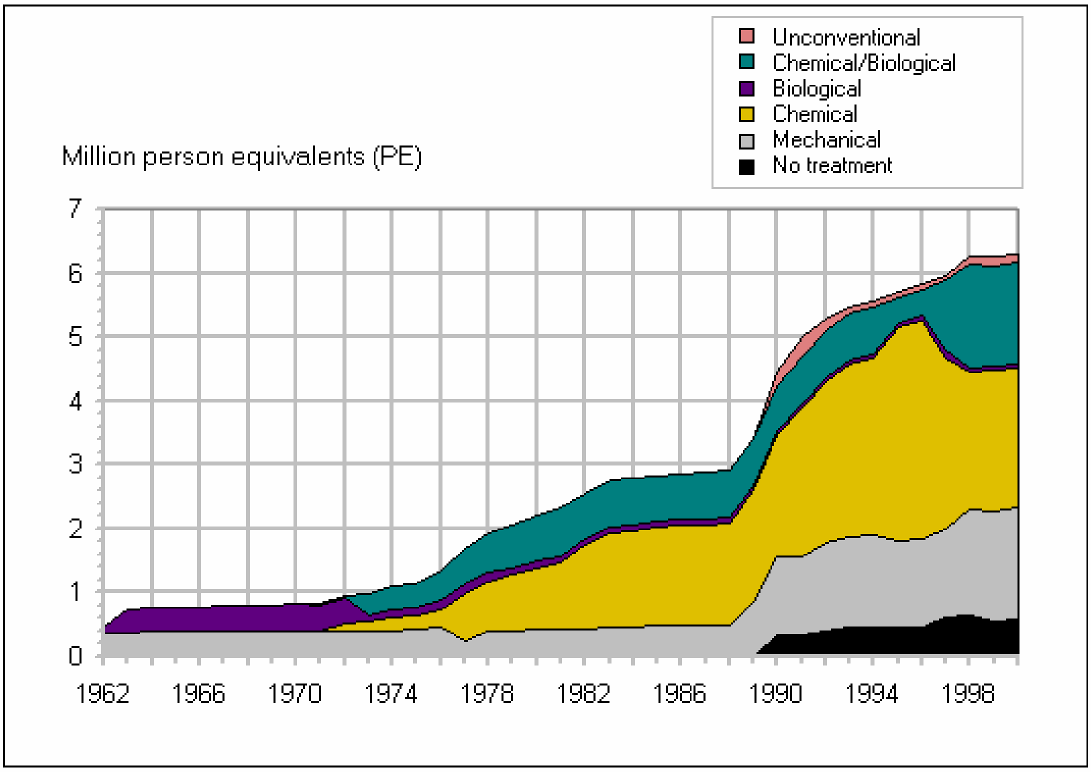


Figure 9. Hydraulic capacity at the WWTs for different treatment processes (data from Statistics Norway).

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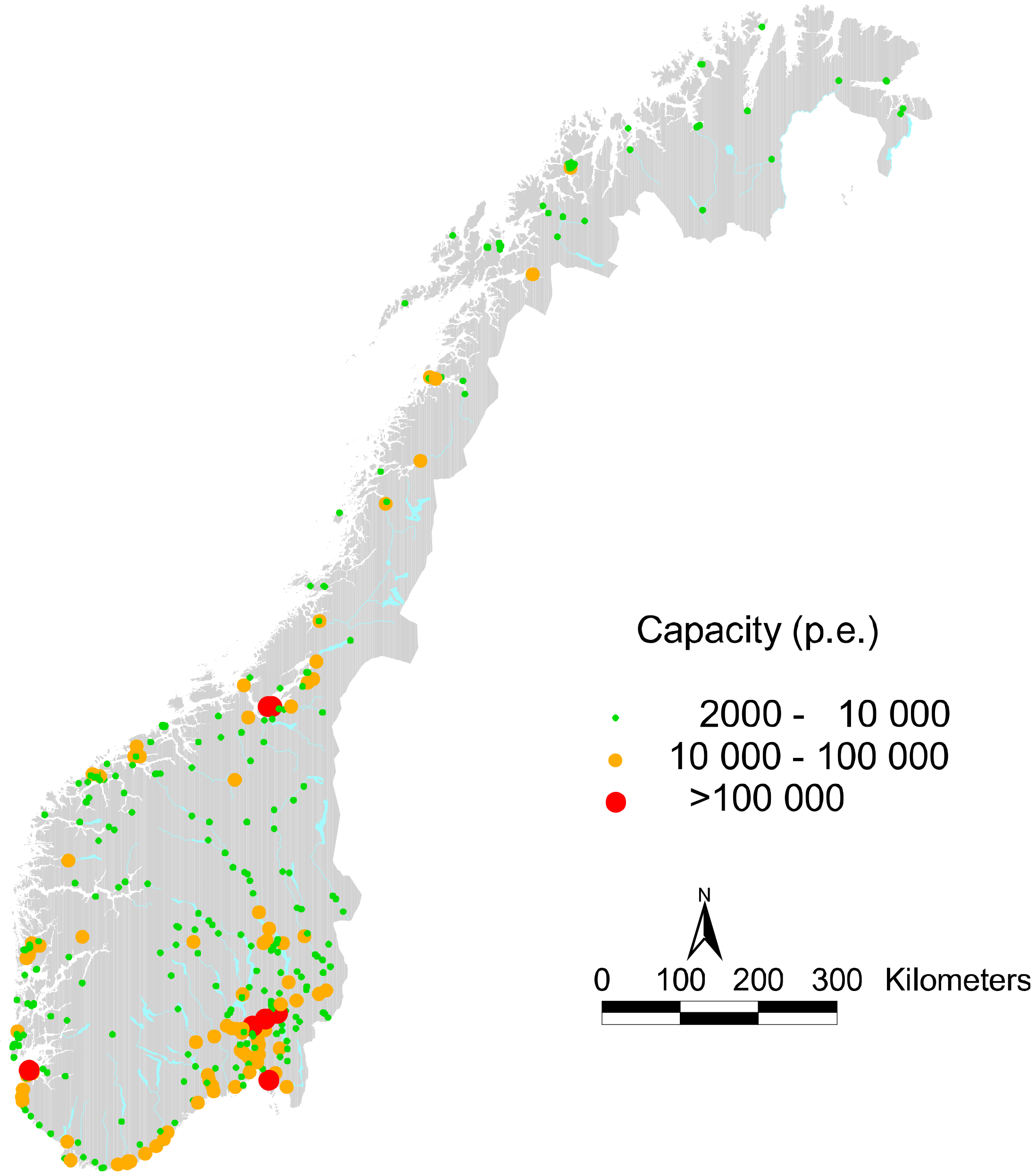


Figure 10. Treatment plants with capacities exceeding 2000 PE.

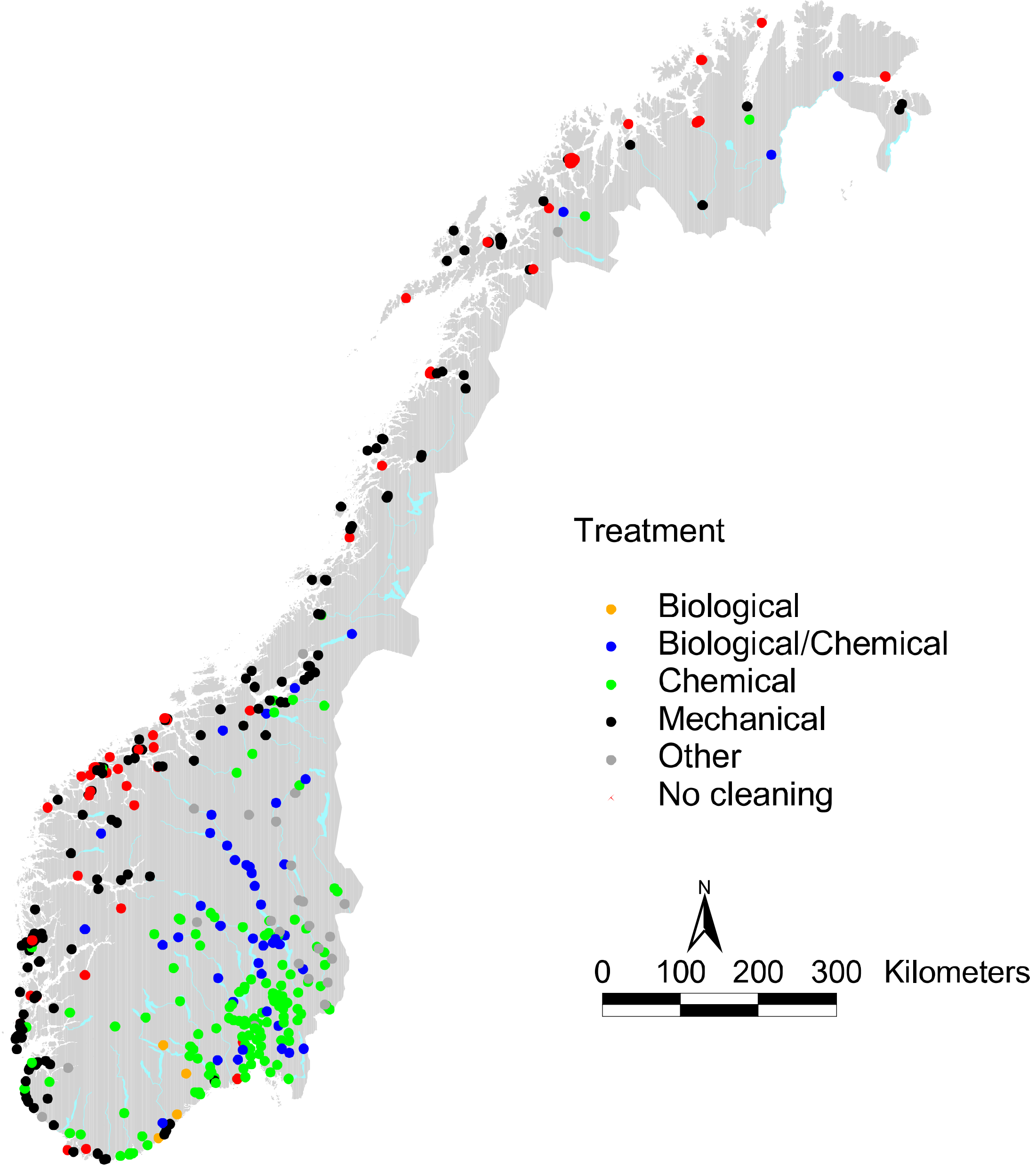
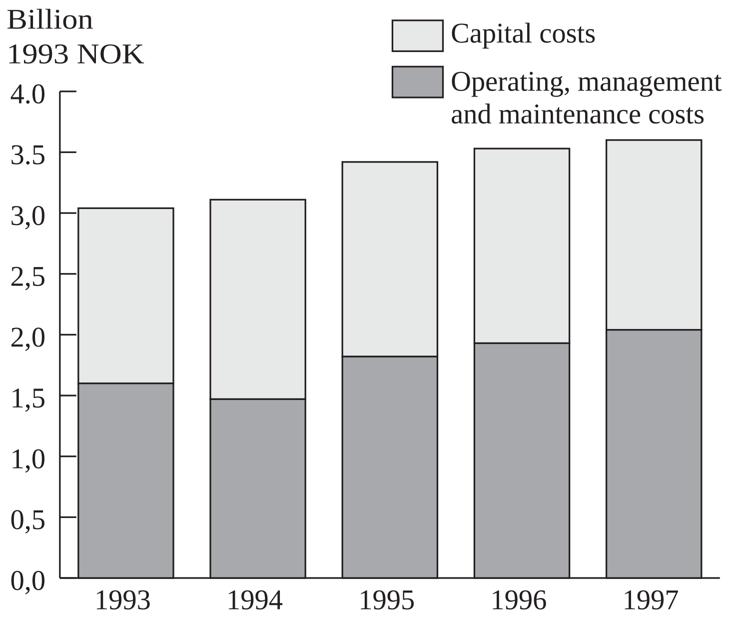


Figure 11. Treatment processes applied in wastewater treatment plants.



Source: Waste water treatment statistics from Statistics Norway.

Figure 12. Total costs in the municipal wastewater treatment sector, whole country. Constant 1993 NOK (1 EURO = 8 NOK). (Data from Statistics Norway).

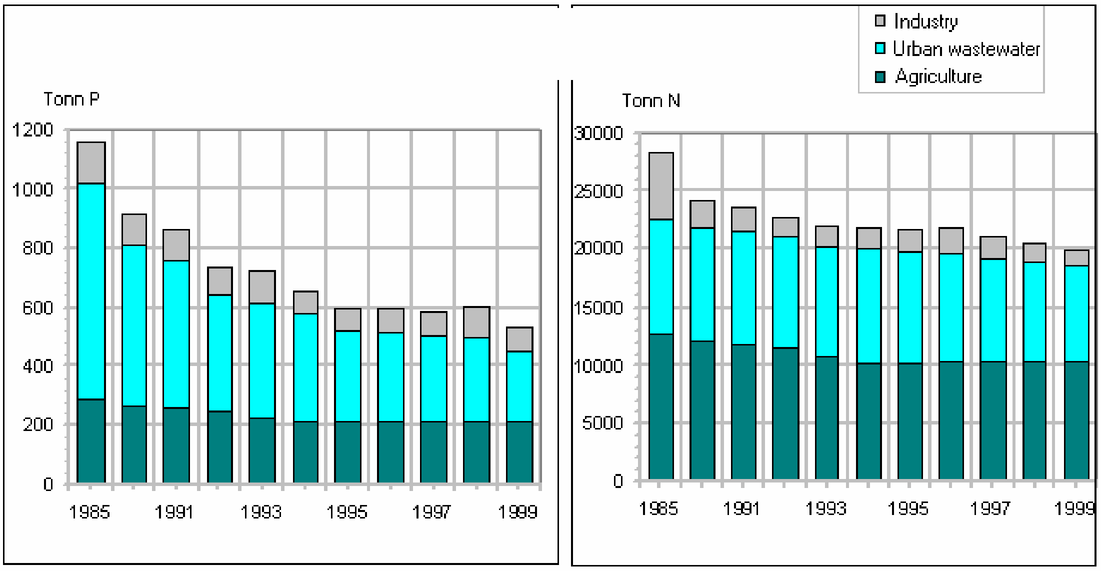


Figure 13. Reduction of the total load of phosphorus and nitrogen from Norwegian industry (top), Urban wastewater (middle) and agriculture (bottom), respectively to the coastal zone between the Swedish border and Lindesnes (southernmost point of Norway). (Data from Statistics Norway).

7. Treatment efficiency related to wastewater treatment methods

Wastewater treatment methods can be combined in different ways depending on the raw wastewater quality, the recipients and the permitted discharge values. The quality of the effluents depends also on the efficiency of the operation of the plant.

Based on a survey of Norwegian wastewater treatment plants in the early 1990s (Ødegaard & Skrøvseth 1997), the treatment efficiency for different treatment methods is listed in **Table 5.** The table indicates that the chemical treatment came close to fulfil the requirement of 75 % removal of COD on average. However, the majority of the plants did not. On the other hand, the concentrations of COD in the effluents were usually below the 125 mg/l concentration limit. Note that the BOD is expressed as BOD_7, which has been the national standard in Norway. Correlation analysis has shown that BOD_7 may be converted to BOD_5 by a multiplication factor 0.83 (Nedland 2001).

A more recent compilation of data from 60 of the largest chemical treatment plants showed average removals of approximately 60% for BOD_5 and COD, and effluent concentration of BOD_5 = 38 mg/l. There were, however, large variations between the plants and it was estimated that 38 % of the plants fulfilled the requirement for COD removal. Because of the rather diluted character of Norwegian urban wastewater, the requirement for effluent concentration of BOD is fulfilled by more treatment plants than that on removal efficiency. (Nedland, 2001).

While the chemical treatment process in most cases is not sufficient to reach the required removal of organic matter in secondary treatment, it is more efficient in P-removal than the Directive requirement for discharge to sensitive areas. The average effluent concentration of total P in effluents from 99 chemical treatment plants was 0.42 mg/l (**Table 5**). Another study, including also the larger treatment plants with chemical precipitation showed an average effluent concentration of 0.26 mg/l. It demonstrated also that the largest plants had the lowest effluent concentrations of P. This was explained as a result of more stable conditions and more diluted influents to the larger plants (Ødegaard 1992). The removal of nitrogen in these plants was 28 % on average.

Table 5. Removal efficiencies for organic matter and phosphorus obtained by various wastewater treatment systems in Norway (From Ødegaard and Skrøvseth 1997).

Process	COD		BOD_7		Tot P	
	R %	C (mg/l)	R %[1]	C (mg/l)	R %[1]	C (mg/l)
Chemical	74.8±10.0	108±62.0	71.9±16.6	48.7±38.9	90.6±11.0	0.42±0.42
Biological	78.9±8.1	88.6±40.9	81.9±11.5	34.7±19.1	52.9±20.5	2.93±1.68
Biol./Chem.	84.5±7.3	60.0±26.2	89.3±7.3	18.9±21.7	91.1±8.7	0.52±0.51

[1] Treatment efficiency based on individual samples

The chemical precipitation process results in an efficient removal of suspended solids (approx. 90%) from the wastewater, which is important since metals and organic micropollutants are mainly associated to the particulate fraction. A study at a chemical treatment plant in the Oslo area (Ødegaard 1992) showed removal efficiencies from 50 % (Zn, Hg) to 83% (Cr) for various metals. An additional benefit of the removal of suspended solids is that it also results in an efficient reduction of bacteria in the wastewater.

8. Effects of urban wastewater in rivers, lakes and marine waters

8.1 Method

The low population density and the high discharge of freshwater indicate that the receiving water capacity in Norway is generally high. However, because of the uneven distribution of population and the water resources, it is necessary to make assessements at regional and local levels.

A model, which covers all catchment areas in Norway, was used to calculate the loading of organic matter from urban wastewater. The catchment areas were divided into approximately 1000 statistical sub-areas. Data on loading of TOC, P and N from wastewater, including calculated loads from scattered populations were available for each sub-area. These loads were either based on measurements or calculated from the numbers of person equivalents and the efficiency of the wastewater treatment methods used. For TOC, the following figures were used:

Load: 23 g TOC/person, day
Leakage and overflow on the sewerage system: 10%
Efficiency of TOC removal:
    Mechanical treatment: 30%
    Chemical treatment: 65%
    Biological treatment: 85%
    Chemical/Biological treatment: 90%
    Soil filter/other methods, which includes scattered populations: 85%.

The calculated TOC loads were divided by the mean annual water flow in the recipient watercourses. It was assumed that TOC is transported as a conservative matter downstream to the sea. This means that the calculated concentration at each point includes the total load upstream of that point. This is a very conservative estimate since it assumes that no degradation of organic matter is taking place. The calculations show, that even with this very conservative assumption of non-degradation, the accumulated load of TOC from urban wastewater in Norway rarely exceeds 2.5 mg/l. This represents the upper limit for the best quality class in the Norwegian water quality classification system (see **Figure 14**).

8.2 Rivers and running waters

The calculated TOC loads indicate that the oxygen consumption due to wastewater discharge is low compared to the capacity of the receiving waters. For most watercourses, the accumulated loads would not be sufficient to cause de-oxygenation of the water even if complete degradation occurred and the supply of oxygen from the atmosphere was excluded. In practice, re-oxygenation by diffusion from the atmosphere is effective in most rivers because of the rapid, turbulent flow. Therefore oxygen depletion in rivers, as an effect of discharges of urban wastewater, has not yet been observed in Norway. Consequently, dissolved oxygen is not included as a monitoring parameter for water quality in running waters. This fundamental different situation in Norway, as compared to most of central Europe, in this respect is illustrated in **Figure 15** which shows the average concentration of organic matter in several European rivers.

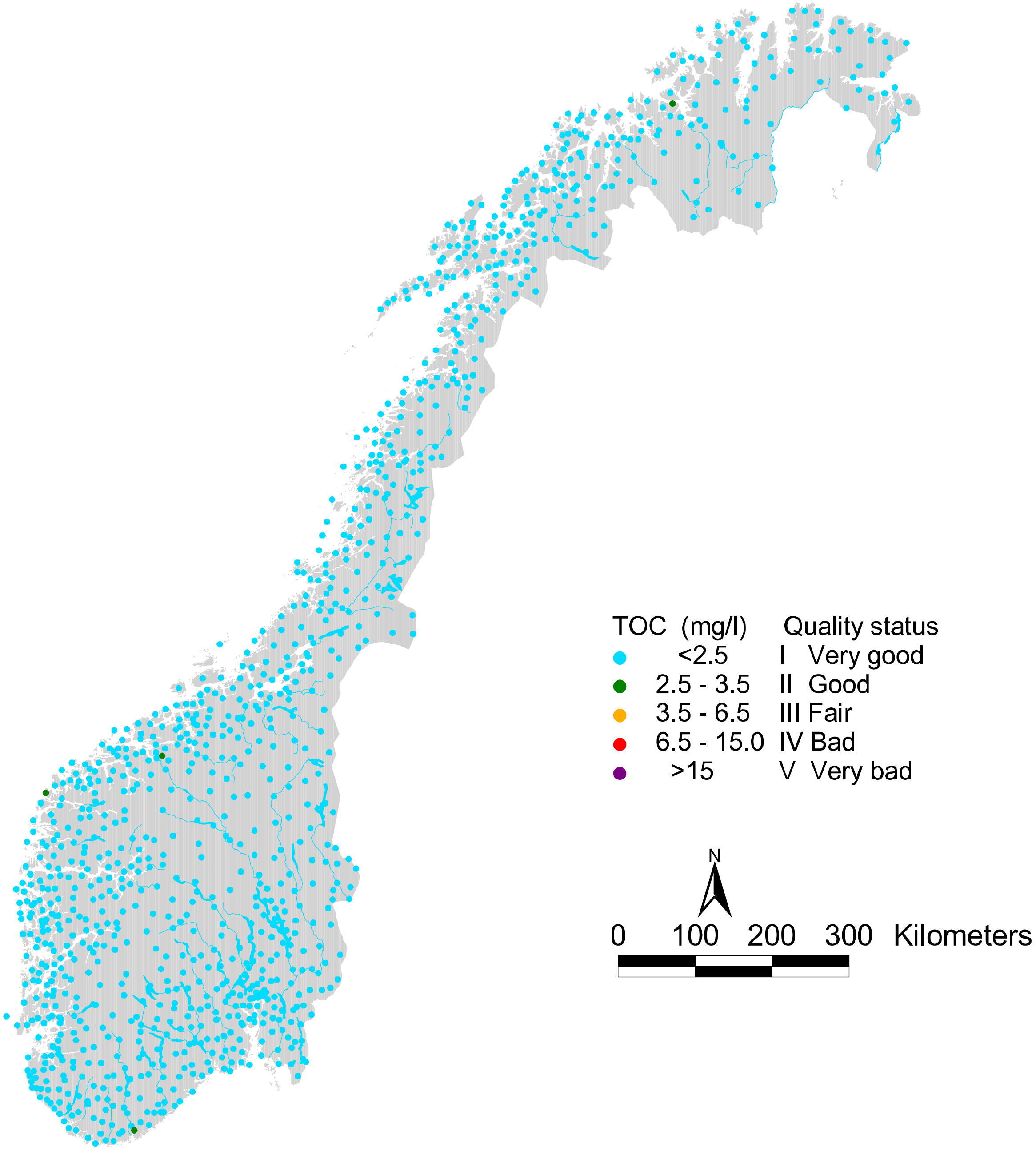


Figure 14. Calculated TOC concentrations based on wastewater loading and receiving water capacity in 1100 sub-areas. The colour scale indicates the water quality classification based on TOC.

8.3 Lakes

While de-oxygenation is not a problem in Norwegian running waters, the situation is different in certain lakes. Many of the drainage areas in Norway encompass lakes of various size and morphology. Except for the very shallow lakes, most lakes are stratified during summer and winter periods with circulation periods in spring and autumn. Oxygen depletion in the hypolimnion may occur when the oxygen consumption due to degradation of organic material exceeds the oxygen reserves in the water.

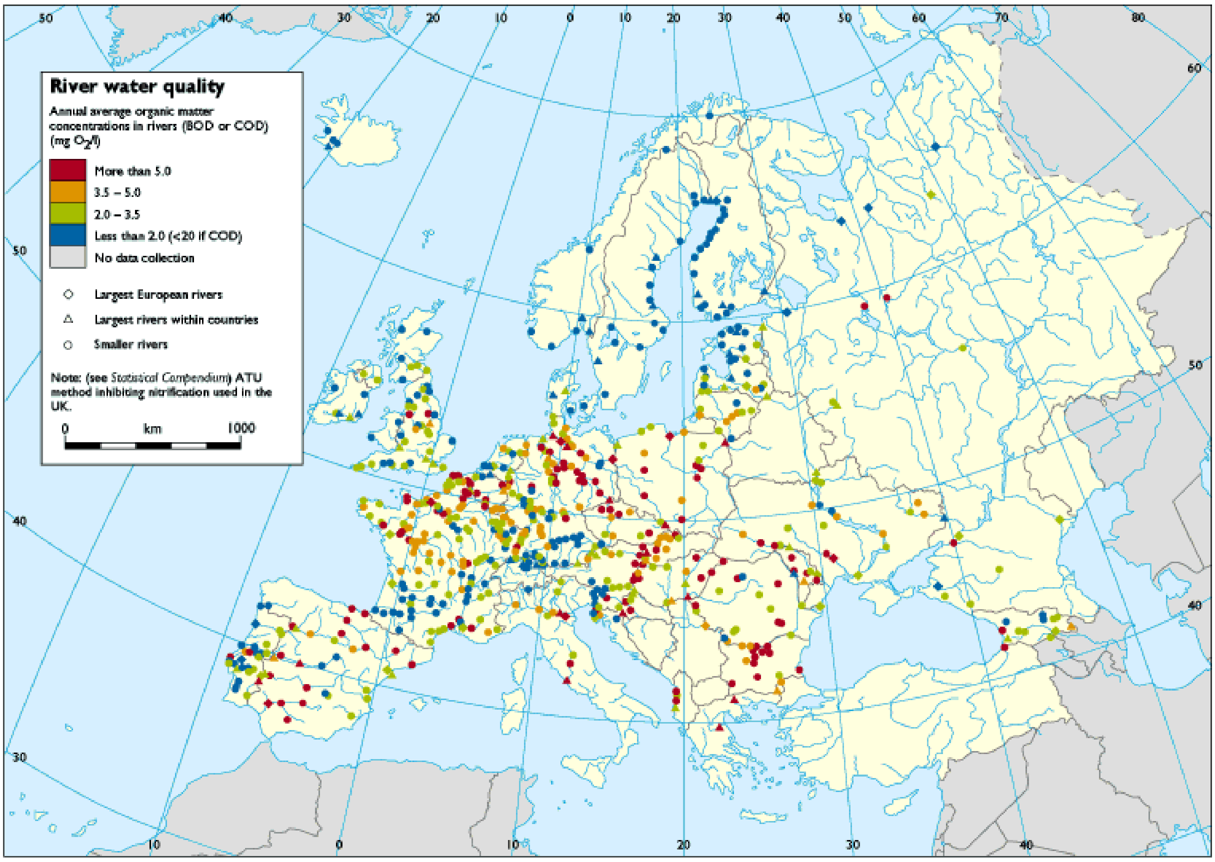


Figure 15. Annual average organic matter concentrations in rivers, expressed as biochemical oxygen demand (from EEA 2001).

The organic load causing oxygen consumption in the deep waters of lakes originates from natural and anthropogenic sources. The main source is often organic material produced by photosynthesis in epilimnion. This process is stimulated by supply of inorganic plant nutrients, mainly phosphate and nitrate. Increased loads of these nutrients from agriculture and wastewater discharges have caused eutrophication of lakes and rivers. In severe cases, excessive growth of algae has caused practical problems for the utilisation of the water resources. This secondary organic load caused by plant nutrients exceeds substantially the primary load of organic material from wastewater. Theoretically, the amount of organic matter that can be produced as algal biomass from a certain amount of phosphorus can be calculated from the elementary composition of algal biomass. Redfield et al. (1963) found that the atomic C:P ratio in marine plankton was on average 106:1. This corresponds to a P-content in plankton of approximately 1.2 %. In P-limited freshwater algae, much higher C:P ratios can be found. The algal growth potential (AGP) of the green alga *Selenastrum capricornutum* in P-limited medium is e.g. 560 g biomass/g P. This means that the P-content in the algae is approximately 0.2 % (see **Figure 16**).

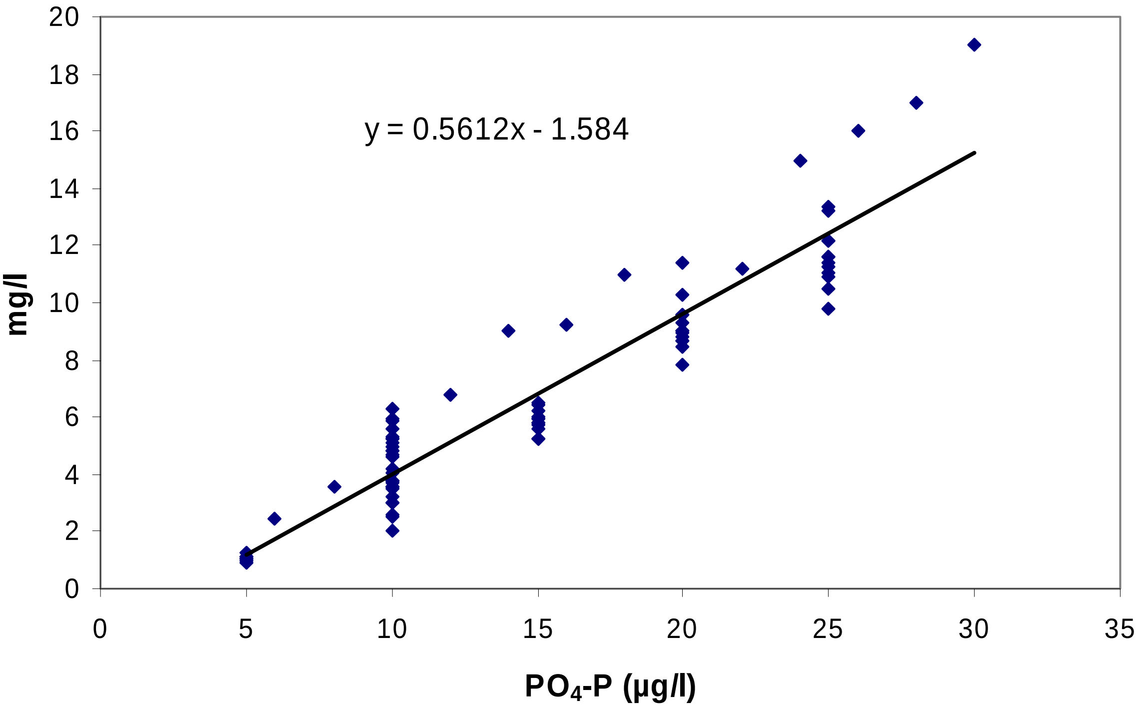


Figure 16. Production of algal biomass in AGP-tests as a function of P-content in the water. The tests were performed with the green alga *Selenastrum capricornutum* (data from Norwegian Institute for Water Research).

The P-load from one person in Norway to the wastewater has been estimated at 1.6 g/day. Using the yield factor for *S. capricornutum* (**Figure 16**), this amount of P can be converted to approx. 900 g algal biomass. This represents a theoretical oxygen consumption of approx. 1000 g O_2 for complete aerobic degradation. This secondary oxygen demand is 15 times higher than the typical primary oxygen demand for Norwegian wastewater of 60 g (measured as BOD).

The importance of the secondary organic load as compared to the primary load from wastewater discharges is further emphasised by the fact that most of the organic matter in the wastewater is readily degradable, and the degradation takes place in the well oxygenated surface waters. The secondary load of organic matter (plankton algae), on the other hand, causes an oxygen demand only after sinking below the photosynthetic zone. Consequently, the oxygen demand is expressed mainly in the hypolimnion, where the supply of oxygen is restricted.

Since eutrophication and secondary organic load have been identified as the major problems caused by discharge of domestic wastewater, the strategy for wastewater treatment in Norway has been focused on removal of nutrients, primarily P, which is the limiting plant nutrient in most Norwegian freshwater systems. While conventional secondary treatment, as in the activated sludge process, has a limited effect on the phosphorus removal, chemical precipitation after primary treatment yields 90% or higher P-removal (see **Table 5**) on wastewater from different treatment processes (see **Figure 17**). The fact that the reduction in growth potential is higher than the reduction of total P is an effect of reduced biological availability of the P remaining after chemical treatment. Biological (secondary) treatment, on the other hand, converts most of the total P in the wastewater to phosphate, which is the most readily available source of P for the algae.

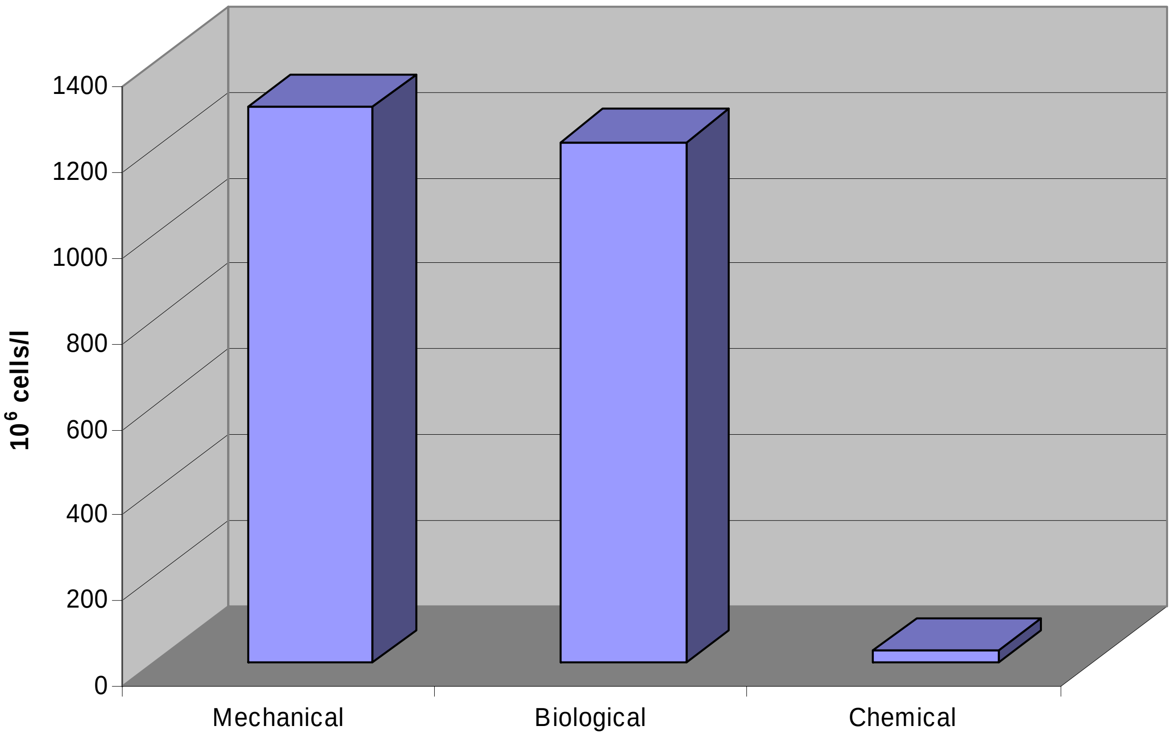


Figure 17. Algal growth potential expressed as cell yield of the green alga *Selenastrum capricornutum* in municipal wastewater after mechanical (primary), biological (secondary, activated sludge) and chemical treatment (precipitation with aluminium sulphate after primary treatment). The wastewater samples were diluted to 5% concentration in natural, oligotrophic lake water (data from Norwegian Institute for Water Research).

As was shown in section 8 7, the current practice with predominantly chemical wastewater treatment has led to a more efficient P-removal than required for discharges of P to sensitive areas according to the Urban Wastewater Treatment Directive. The concentrations of total-P in the effluent is usually 0.2-0.4 mg/l, while the Directive requirement is <2 mg/l. On the other hand, the BOD concentration in the effluent from chemical treatment plants in Norway is higher (average 38 mg/l) than the Directive requirement (25 mg/l).

Under the conditions present in Norway, where the most critical situation related to organic load applies to deoxygenation of bottom water in deep lakes, chemical treatment of wastewater is expected to give a better result than treatment designed to fulfil the Directive criteria for sensitive areas. To exemplify this, the theoretical total organic load for the following two alternative situations have been calculated:

- Chemical treatment (average Norwegian treatment plant).
- Secondary, biological treatment fulfilling the Directive requirement for discharge to sensitive areas.

Since the oxygen demand is realised in stagnant deep water, the ultimate BOD, rather than BOD_5 should be considered. This is assumed to be 90% of the COD. Using the average measured concentrations of COD in Norwegian chemical and biological treatment plants (**Table 5**) provides an estimate of primary ultimate BOD loads of 97 and 79 mg/ respectively in chemically and biologically treated wastewater.

The secondary organic load is calculated as the biomass of algae that can be produced from the amount of P in the wastewater, using the yield factor shown in **Figure 16**). The P concentration is set to 0.42 mg/l for chemical treatment wastewater (**Table 5**) and 2 mg/l for biological treatment, in line with the requirements of the Directive. The ultimate BOD for degradation of algal biomass is set to 90% of the theoretical oxygen demand.

Figure 18 shows the results of the calculations. They indicate that the total oxygen demand may be 3.6 times higher in wastewater fulfilling the Directive requirements, than in an effluent from an average Norwegian chemical treatment plant.

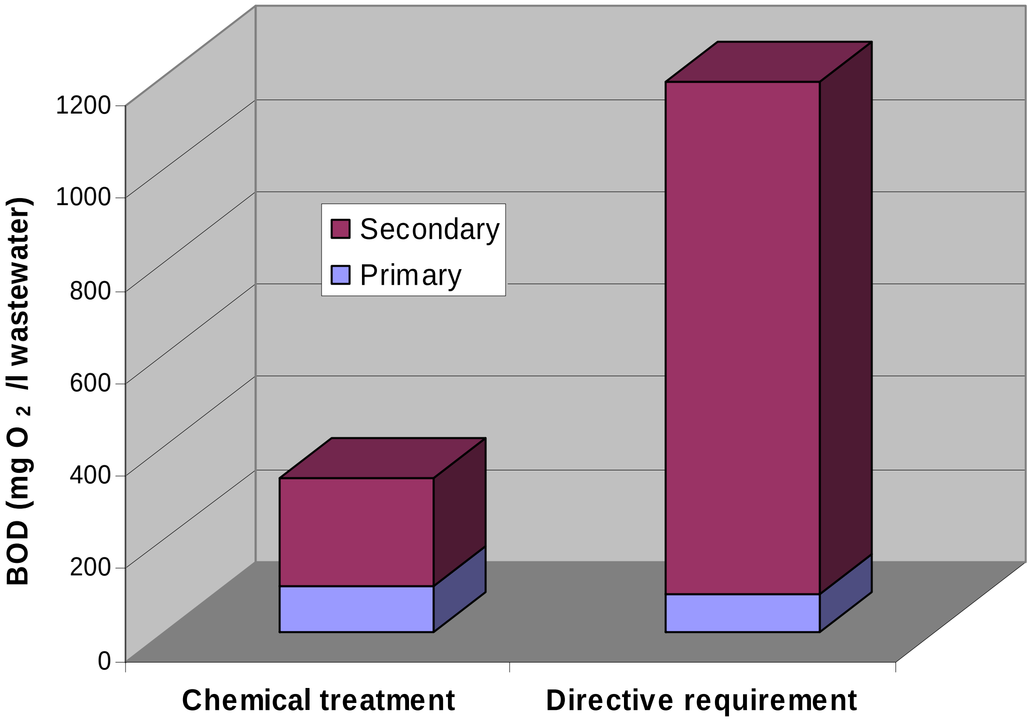


Figure 18. Primary and (calculated) secondary organic load (as BOD) estimated on the basis of different wastewater treatment alternatives.

Development of heterotrophic growth (fungi and bacteria) is another effect of organic pollution, that has to be considered with regard to wastewater treatment.

In Norway, mass occurrence of heterotrophic growth of fungi and bacteria in running waters has mainly been caused by industrial wastewater and losses from agricultural activities. In sewered areas, the recipient adapted strategy ensures that adequate treatment is applied to exclude significant heterotrophic growth in the receiving waters. In most cases, the chemical treatment, which is primarily applied to reduce the P-load, also gives sufficient reduction of organic matter to fulfil the environmental objectives. Where this is not the case, biological or chemical/biological treatment is applied. Local problems with heterotrophic growth may, however, still occur in small creeks in areas with scattered population, not connected to public sewers.

8.4 Coastal waters and fjords

In view of the large variations in marine recipients along the Norwegian coast, topographically as well as with regard to water exchange dynamics, the basic principle in the policy concerning waste-water treatment has been to adapt the requirements to the local conditions. In most open recipients with high oxygen capacity, a combination of purification and technical arrangements, ensuring optimal dispersion of nutrients and suspended matter, have been applied. In sill fjords and more sensitive systems, high-grade purification has been implemented, or, which in many cases has been feasible, primary treated effluents have been transferred to more open receiving waters.

In these systems, a combination of purification and technical arrangements of the outfalls, which ensure entrainment of effluent waters at intermediate levels in the water column, have been much used since the 1980s. The effluent outfalls are deeply submerged, e.g. at 30-50 m depth. They are often supplied with diffusor arrangements to obtain deep trapping and high initial dilution of the plume (typically 15-25 m depth and 50-75xdilution) during the summer. Nutrients and suspended material are rapidly dispersed and diluted, and effluent components can generally be traced only very close to the outfalls. These outfall arrangements are preferred for hygienic reasons as they bring the outfall away from the shore. Furthermore, the nutrients are dispersed below the most productive surface water layers (**Figure 19**).

The effects of wastewater dicharges to marine waters may be assessed by using the same principles as for lakes. However, the situation in marine waters is more complicated than in fresh water systems. In marine waters, nitrogen is generally considered as the limiting nutrient. However, in areas that receive a heavy inflow of nitrogen-rich freshwater, phosphorus may be the limiting nutrient more often than nitrogen (c.f. the situation in the outer Oslofjord, ANON 1996). Based on AGP-tests with marine algae and theoretical calculations from a C:N:P-ratio of 106:16:1, it can be demonstrated that the secondary oxygen demand, caused by degradation af algae, is far higher (5-10x) than the typical primary oxygen demand for Norwegian wastewater of 60 g (measured as BOD).

The importance of the secondary organic load, as compared to the primary load from wastewater discharges, is further emphasised by the fact that the secondary treatment removes most of the organic particles in the wastewater. The remaining organic matter is readily degradable. This also implies that degradation takes place in the water column between the surface and 15-25 m depth, in a water body that normally is well oxygenated due to contact with the atmosphere and rapid water renewal. The secondary load of organic matter (plankton algae) causes a significant oxygen demand only when it sinks below the photosynthetic zone and to the bottom where the water exchange and supply of oxygen may be restricted

The following sections describe three different types of recipients: coastal water, open fjords and fjords with restricted water exchange (**Figure 20**).

Coastal waters
As described in section 3, the coastal waters generally flow along the Norwegian Skagerrak coast and the Norwegian west coast as a vey large river. The typical flow along the Skagerrak coast is 250 000 m^3/s. Assuming an average oxygen concentration of 8 mgO_2/l, this corresponds to a transport of 2 tons O_2/s or 60 mill. tons of oxygen/year in the Skagerrak coastal waters. Although only the upper and inner part of the NCC is in direct contact with sewage from outfalls in the outer skerries and the coastal current, this oxygen supply far exceeds a COD of 118 000 tonnes from degradation of organic matter from the outfalls (Holtan et al., 1997). However, as pointed out in section 4.2, there has been a regional decline in oxygen concentration of the coastal water “upstream” of the Norwegian Skagerrak coast since 1980.

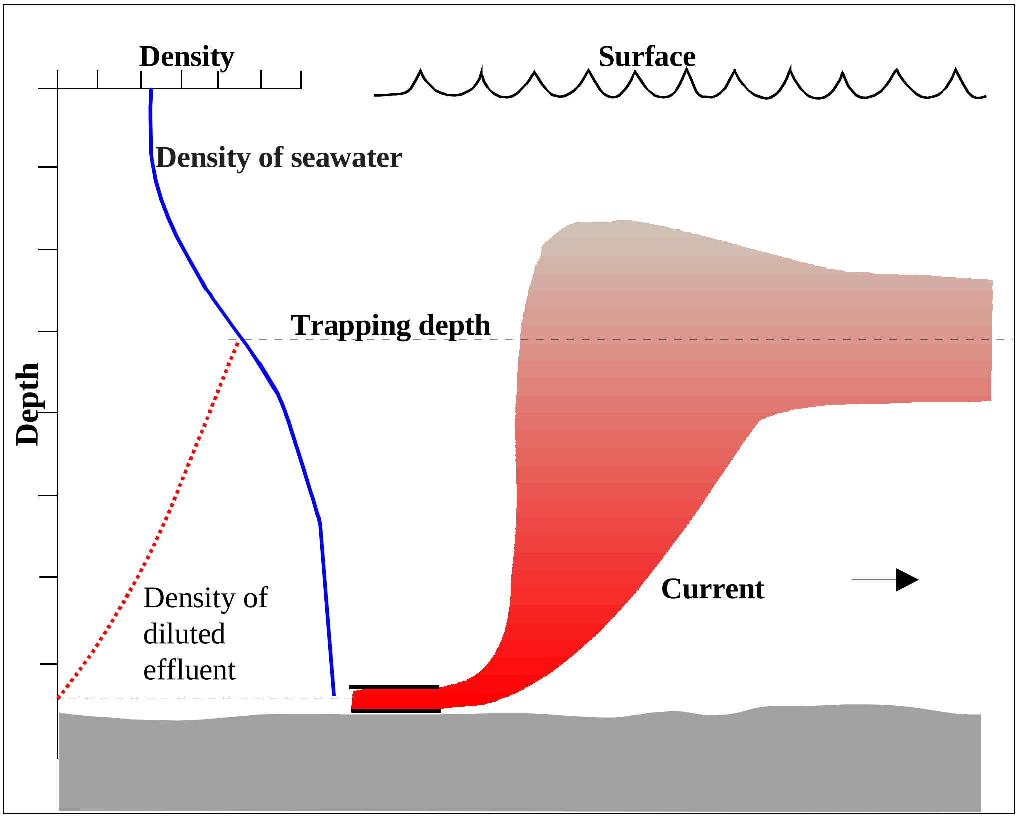


Figure 19. Example of deep water outfall with trapping of effluent below the surface.

On the Norwegian west coast and further to the north, the NCC transports 1 million m^3/s or more. We have seen that the relatively few direct discharges of municipal sewage will not affect the oxygen concentration in this water body. The remaining problem would be possible effects of organic matter in fjords and other inshore waters.

Open fjords

In fjords, the conditions are in principal similar to the situation in lakes, but the oxygen capacity depends heavily on the water exchange dynamics. In most fjords, the water masses are more or less stratified during the year. Both surface and intermediate waters (down to a possible sill depth) stay in open connection with outside waters and may be fully exchanged in the matter of days or weeks. Fjords with open topography and deep or no sills will therefore have a high and rapid water exchange with the coastal waters. For a fjord with a sill at 40 m depth, the FjordEnvironment model (Stigebrandt 2001) gives an average water exchange of 40-50 m^3/s pr. km^2. In this type of fjords, oxygen problems occur only in cases with extreme oxygen consumption.

In open fjords with relatively deep sills (>30 m), the water exchange above sill depth is sufficiently high to flush most of the sinking organic matter from the primary production out of the fjord before it sinks below the sill depth and enters the basin water. In these cases, the water renewal of the basin water behind the sill is usually sufficient to avoid serious oxygen problems.

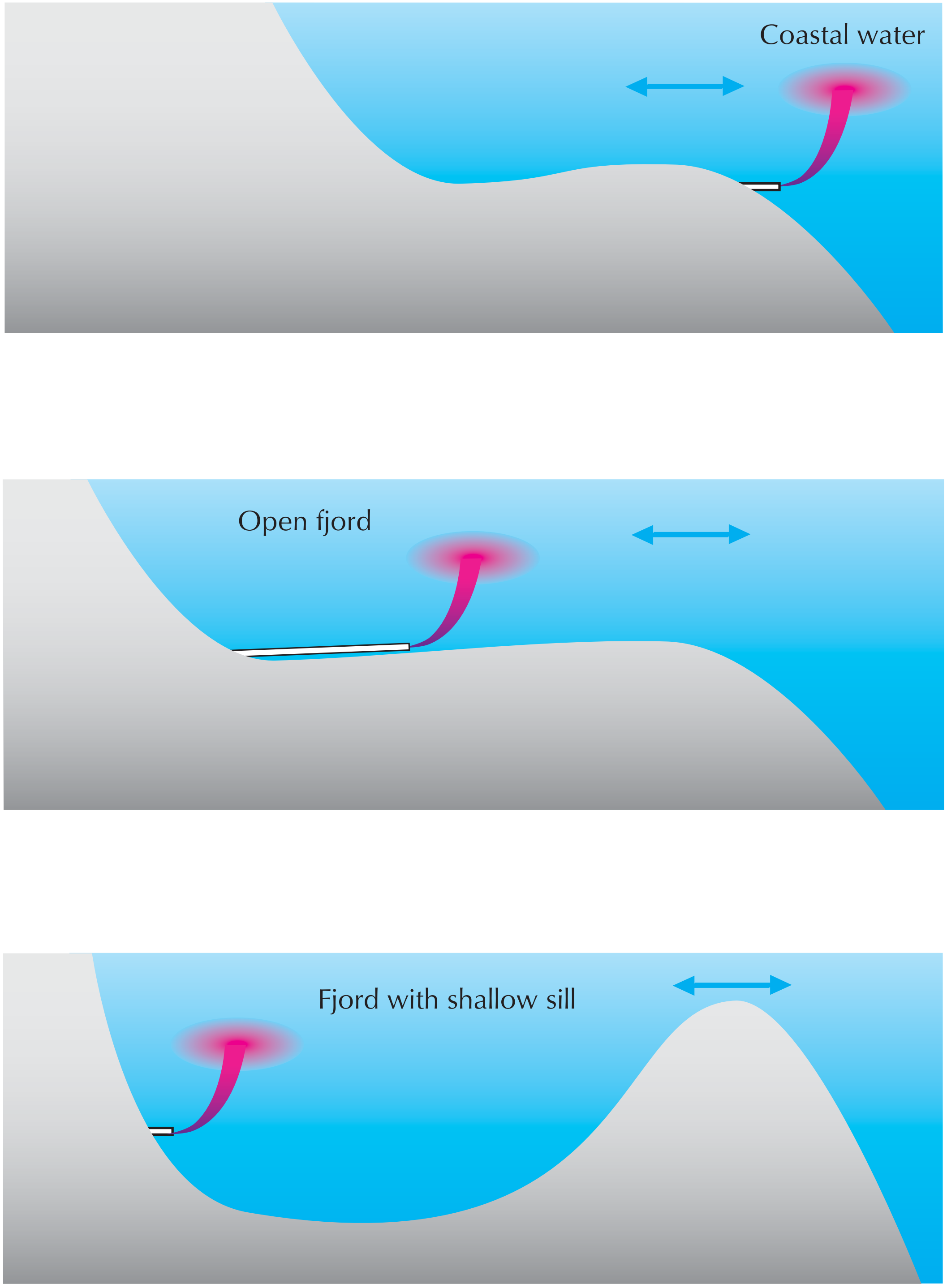


Figure 20. Three main types of marine recipients. The directions of the water exchange is indicated with arrows.

This principle has been documented and demonstrated for nearly 30 fjords on the west coast of Norway (Aure and Stigebrandt 1989 a,b). The Topdalsfjord near Kristiansand may serve as an example (see **Figure 32**). The main characteristics are given in **Table 6**, where the residence time for the surface brackish layer and the intermediate layer is calculated by the “FjordEnvironment” model. In summer, a typical secchi depth is 4 m; indicating that the primary production mainly takes place above 10 m depth, or more than 30 m above the sill depth. The model assumes that organic particles from the primary production on average sink 1.5 m/day, or in this case 20 days or more to pass through the intermediate layer and into the more stagnant basin water. Compared to an average residence time of 8 days for the intermediate water, this shows that very little or none of the organic load from primary production will reach the basin water and contribute to oxygen problems.

Table 6. Characteristics for the Topdalsfjord

Area	8.7 km^2
Max. depth	75 m
Sill depth	35 m
Average fresh water runoff to the fjord	65 m^3/s
Residence time for surface layer	1.5-2.5 days
Average residence time for the intermediate water (water between surface layer and sill depth)	8 days

The basin water of Topdalsfjord experiences periods of stagnation and low oxygen concentrations. However, this is mainly explained as an effect from an organic load imported through the water exchange with the southern part of the Kristiansandsfjord and from direct inputs of particulate organic matter from the Topdal river and runoff from areas around the fjord.

Fjords with restricted water exchange

Fjords with shallow or narrow sills, restricted water exchange and periodically stagnant basin water are far more sensitive to organic loading, which accelerates the oxygen depletion in the basin water. In these fjords, the residence time for water above sill depth may easily be sufficiently high to allow the secondary organic load from production of algal biomass in surface waters to sink into the basin water. The residence time for the basin water in these fjords is usually 1 - many years, and the oxygen situation in the water body is very sensitive to any organic load. As the organic load from algal biomass, based on the sewage nutrient load, is far larger than the primary sewage organic load (see more details above), the main component of the Norwegian strategy to preserve the marine environment in these fjords is to reduce the nutrient load – but also to remove organic matter from the sewage.

In addition, these actions constitute a step towards reduced eutrophication and may be important to prevent harmful algal blooms. The water masses are interconnected and the relationships between nutrient conditions and algal blooms are therefore complicated. Furthermore, the effects of imbalances among the nutrients are unclear. There is a risk that algal blooms may be triggered by local conditions and subsequently spread to larger areas.

In addition to nutrients and organic matter, discharges of municipal wastewater contain bacteria, solids and in some cases substantial amounts of metals or organic micropollutants. The Norwegian policy with regard to toxic material is to prevent these from entering the wastewater system. However, in case where problems persists, they are generally reduced by a combination of

- chemical precipitation which removes 90-99% of bacteria/viruses and 70-90% of toxic material (Midttun 1993 and Bratli et al., 1995)
- choosing an open recipient with large volumes of water and high water exchange
- submerged outfall with high primary dilution and trapping of the plume well below the surface layer.

9. Examples on effects on water quality on implementation of the Norwegian policy for wastewater management

9.1 Rivers and lakes

Some examples may serve to illustrate what has been achieved in terms of improvement of water quality in waters receiving wastewater by implementing the current strategy for wastewater treatment in Norway. The examples are from drainage areas in the south-eastern part of Norway, where the highest wastewater loads are found.

9.1.1 Glomma River.

Glomma is the largest river in Norway, with a catchment area of 41767 km^2 in the south-eastern part of the country. The upper part of the river is influenced by pollution from mining industry. Further downstream urban and industrial wastewater are discharged from several locations along the river. The pollution status of the river has been monitored by biological surveys. After upgrading of the wastewater treatment plants to chemical or biological/chemical treatment during the last 20 years, a significant improvement of the quality of the river has been observed. **Figure 21** shows the results of the biological classification of the upper part of River Glomma, based on surveys carried out in the periods 1978-1980 and 1984-1989.

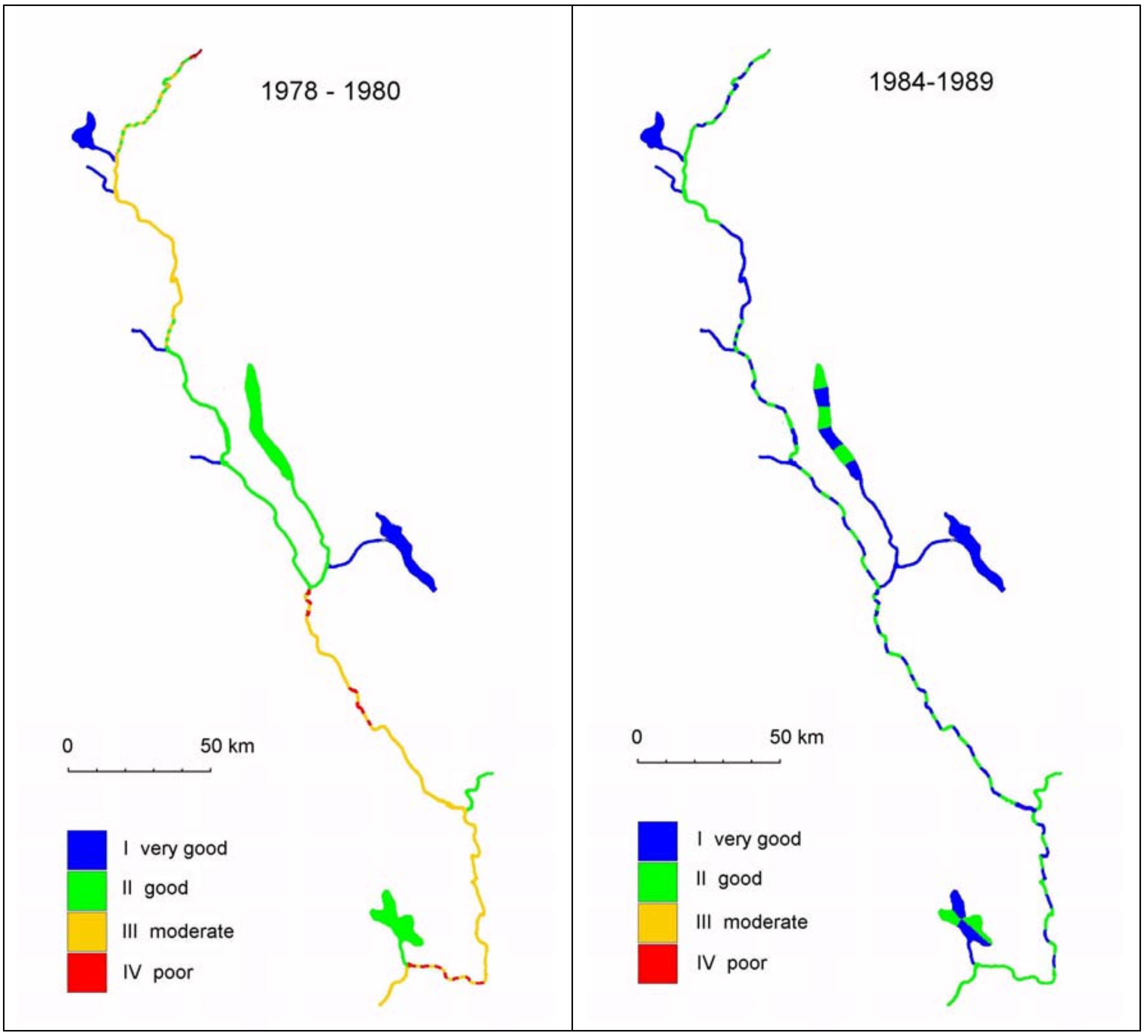


Figure 21. Biological classification of water quality in a section of Glomma River, south-eastern Norway in the periods 1978-1980 and 1984-1989. The classification criteria for the river perifyton community is shown below:

Characteristics	I very good	II good	III moderate	IV poor	V bad
species richness	high	fairly high	fairly high	low	low
biomass of autotrophs	mostly low	increasing, but rare mass occurrences	frequent mass occurrences	Frequent mass occurrences	Frequent mass occurrences
biomass of heterotrophs	negligible	small	moderate	dominant	mass occurrence
species composition (autotrophs)	mainly pollution sensitive species	mixture of sensitive and tolerant species	mainly tolerant species	only tolerant species	only very tolerant species

(Data from Norwegian Institute for Water Research)

9.1.2 Lake Gjersjøen

Lake Gjersjøen is situated some 20 km south of the city center of Oslo, (**Figure 22**). The lake is the main drinking water source of that part of the Oslo-region.

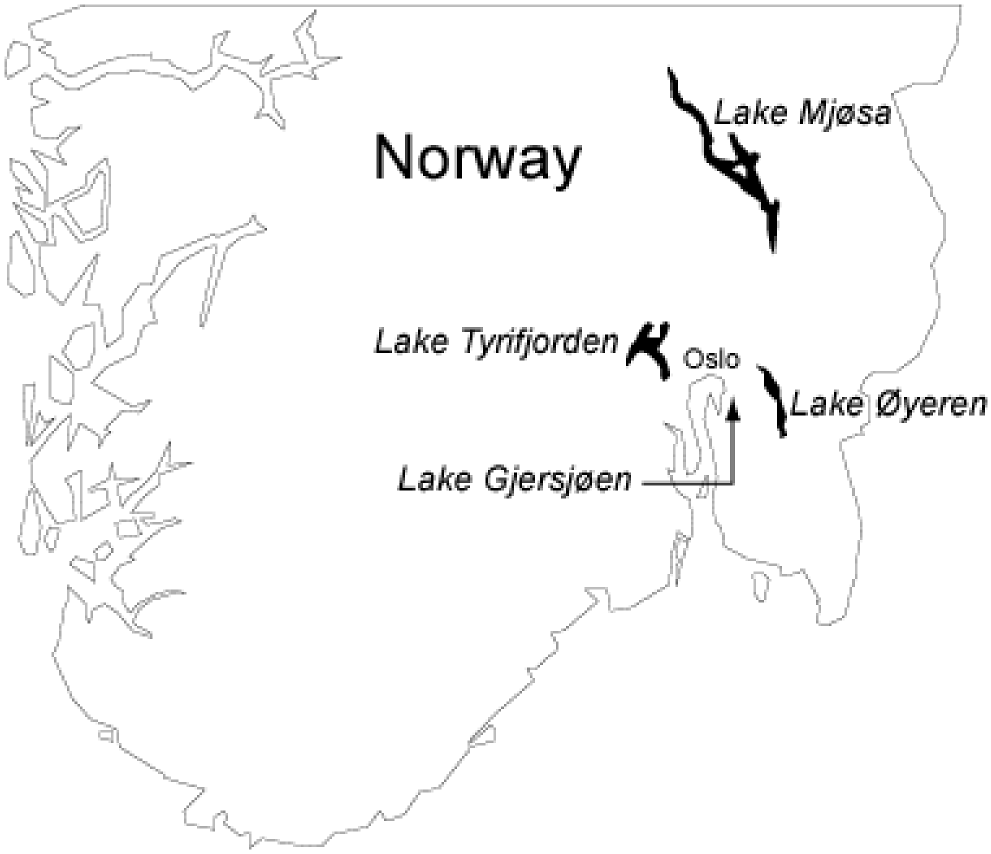


Figure 22. The location of the lakes described.

The lake became increasingly eutrophic during the sixties and seventies. The surface waters were characterised by large amounts of algae, and blooms of blue green algae occurred frequently during the summer. The deep water, from where the drinking water was abstracted, experienced low oxygen concentration at the end of the stagnation periods. The deterioration of the water quality became a big problem for the drinking water supply.

At the south end of Lake Gjersjøen, the Northern Follo wastewater treatment plant was built in 1971 as a primary treatment plant. Intercept sewers along the lakeshores were built at the same time and the effluent discharged into the Bunnefjord, a part of the Inner Oslofjord. In 1982 a chemical precipitation plant with phosphorus removal was built. In 1996, it was further developed to also include nitrogen removal.

The water quality has improved considerably. The algal content has been reduced by about 80%, (**Figure 23**). The oxygen concentration in the deep waters has increased from about 10% to about 80% saturation at the end of the stagnation period (**Figure 24**).

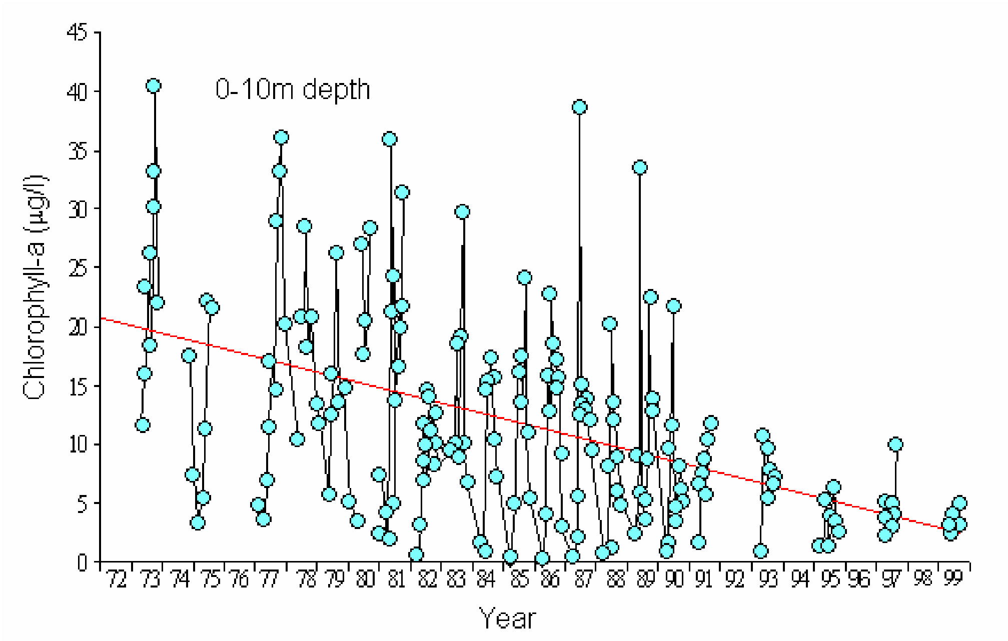


Figure 23. Reduced trophic level, expressed as decline in phytoplankton biomass in Lake Gjersjøen (from Oredalen et al 2001).

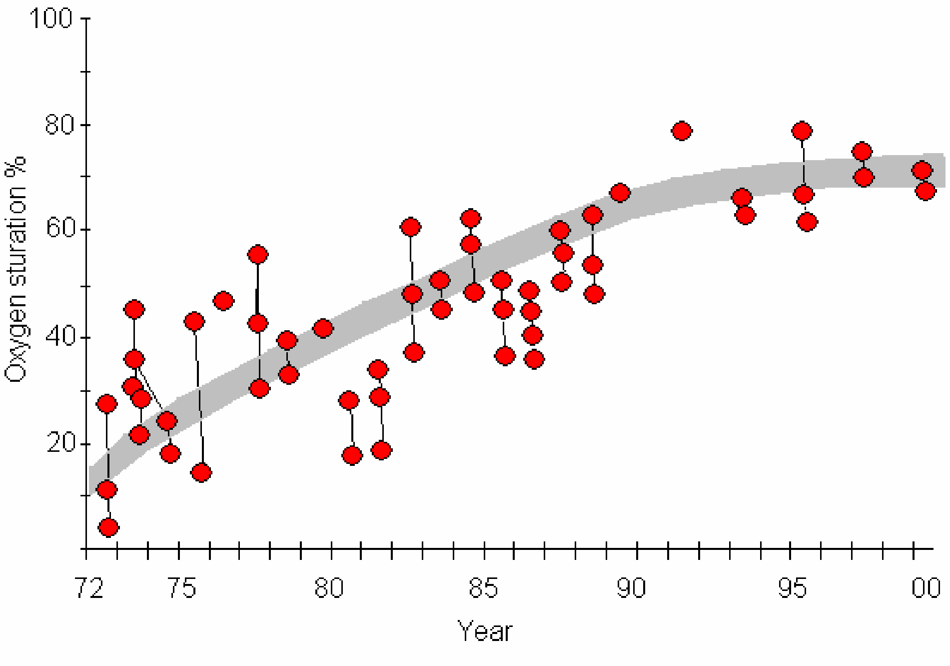


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Figure 24. Reduced trophic level, expressed in terms of improved of oxygen conditions in the deep water of Lake Gjersjøen in the Oslo area (from Oredalen et al 2001).

9.1.3 Lake Mjøsa

Lake Mjøsa is Norway's largest lake with a surface area of 362 km^2 and a maximum depth of 449 m. During the period 1950-1976, the pollution of the lake increased. It peaked in 1975 and 1976 with extensive blooms of blue green algae. The water had a very unpleasant smell, which influenced badly the drinking water supply of approximately 200 000 persons. The smell was almost impossible to remove with the traditional water treatment methods.

In 1976, a massive pollution abatement effort campaign was launched. The main measure consisted of collecting domestic sewage and subsequent phosphorus removal by chemical precipitation. The rehabilitation campaign also comprised measures against agricultural and industrial sources, but the main measure was above all P-removal from domestic sewage.

The results of the campaign are shown in **Figure 25**. The algal content was reduced by 60-80%; the secchi depth transparency increased from 4 m to 8 m (**Figure 26**).

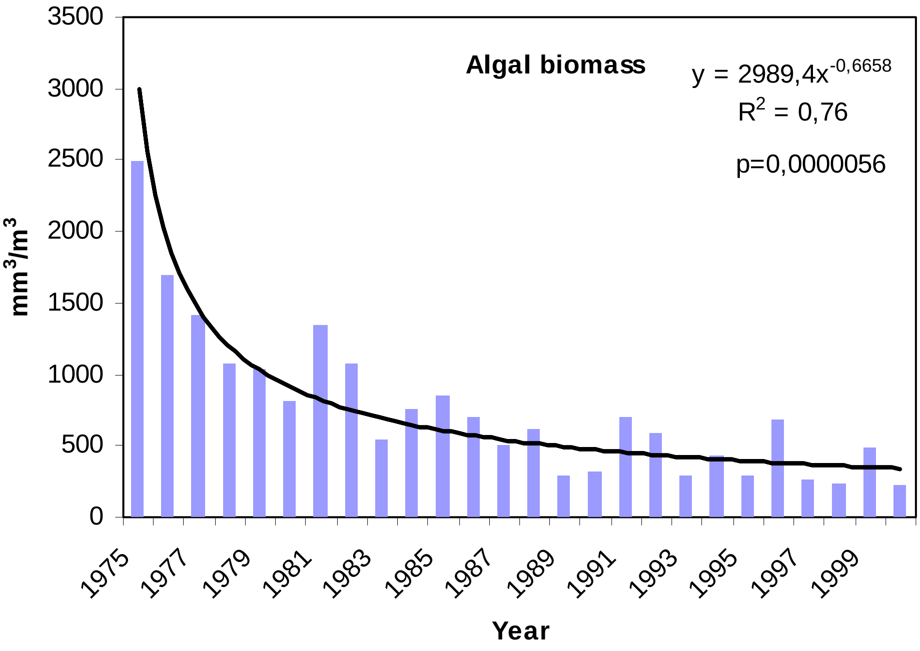

Figure 25. Reduced trophic level, expressed as decline in phytoplankton biomass in Lake Mjøsa, SE-Norway (from Kjellberg et al 2001).

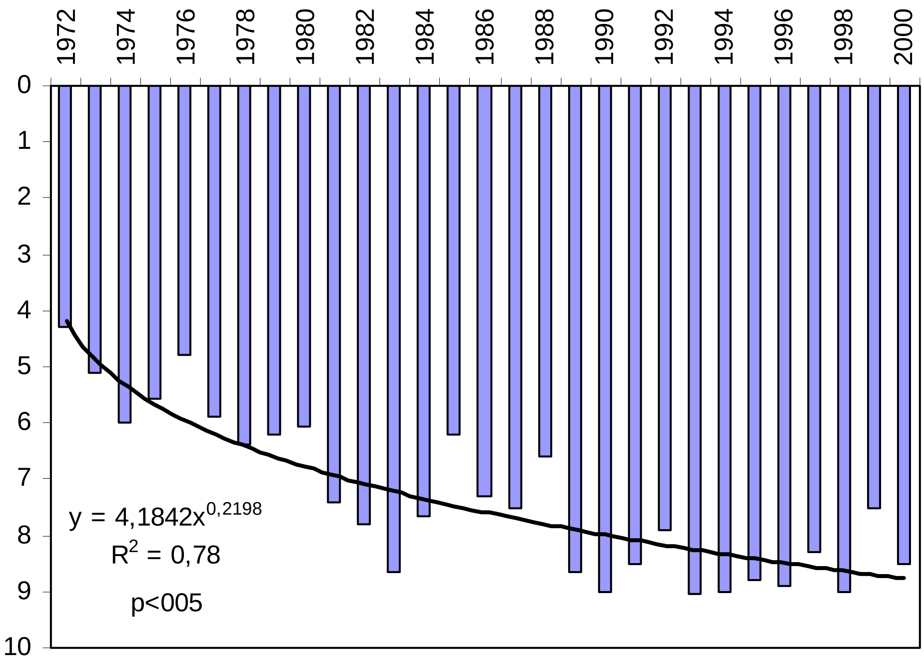

Figure 26. Reduced trophic level in Lake Mjøsa, expressed in terms of increased secchi depth transparency (Kjellberg et al 2001).

9.1.4 Lake Tyrifjord and Lake Øyeren

The situation in the Lake Tyrifjorden and Lake Øyeren is simular to Lake Mjøsa's. The location of the lakes is shown in **Figure 22**.

In both lakes the sewage from about 70-80% of the population (cities, towns and villages) were collected and treated with chemical precipitation. This resulted in a considerable improvement of the water quality. In Lake Tyrifjord, the amount of algae was reduced by 50%; in Lake Øyeren the reduction was about 75%.

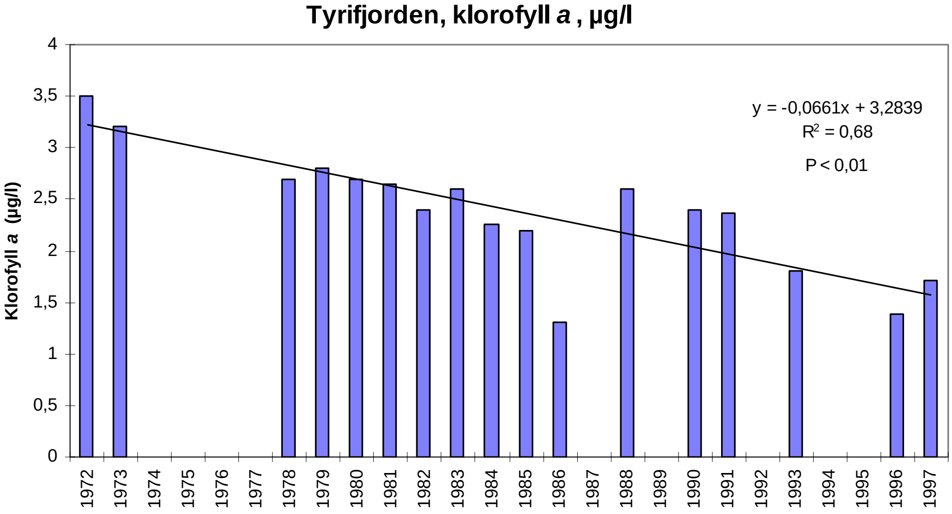

Figure 27. Reduced trophic level in Lake Tyrifjorden in terms of reduced phytoplankton biomass as chlorophyll-a (from Bratli et al 1999).

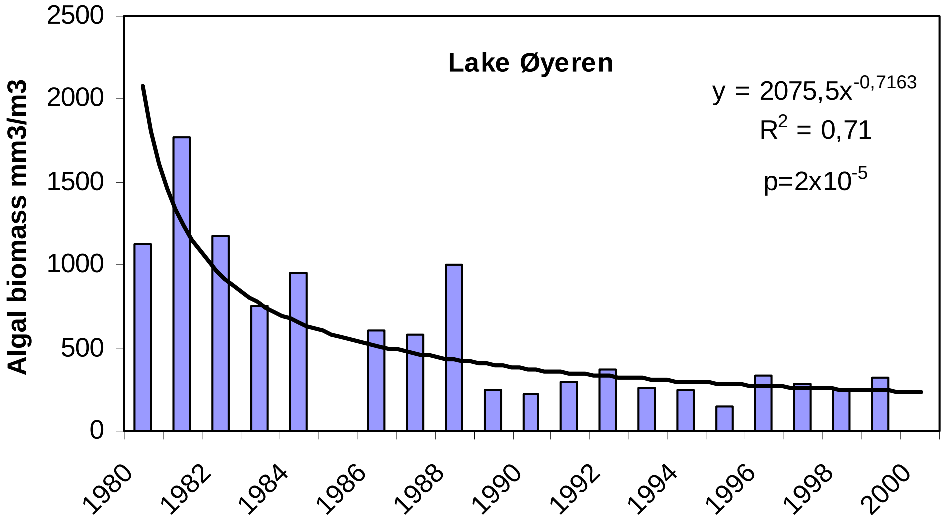

Figure 28. Reduction in trophic level in Lake Øyeren expressed in terms of reduced phytoplankton biomass (after Martinsen 2001).

9.1.5 Discussion

For large Norwegian watercourses (lakes and rivers), the eutrophication due to P-load has been the main problem. It still is in some smaller lakes and rivers. The lakes are more vulnerable to the P-load than plain river stretches. Eutrophication causeschanges in species composition of the algal community in the direction of "weed-species" (often toxic) that are not easily transferred to the next links in the aquatic food chain. The food chain becomes "short-circuited" in that the dead phytoplankton sinks to the bottom. They are then decomposed by microbes, a process that consumes deep water oxygen. When the P-load is reduced by chemical precipitation, the phytoplankton biomass is reduced, and the remaining production is again transferred as energy into the aquatic food chain, instead of depleting oxygen from deep waters.

Except for Lake Gjersjøen, the other above-mentioned lakes are large and deep with excess oxygen reserves compared to the load of organic matter (included the decomposition of dead algae). That means that the oxygen concentration in the deep waters never was a problem in these lakes. It was close to 100% saturation even in the most polluted period. This is due to the water depths of several hundred meters and the large water renewal, combined with a short growth season. There is so much oxygen present in these huge water columns that even if the lake became eutrophic with respect to algal growth, the settling algal biomass would decompose in the water columns without any significant impact on the oxygen concentration. Most of the BOD in the wastewater discharges are decomposed in the circulating surface waters and does not even reach the deep waters.

Lake Gjersjøen is smaller and more shallow (70 m deep) than the other lakes. The magnitude of the hypolimninon (deep waters) in this lake is relatively small. In the most polluted period in the sixties and the seventies, the organic deposition from the dead phytoplankton was large enough to remove almost all the oxygen from the deep waters. Today, after the rehabilitation campaign, the lake does not suffer from any oxygen problems.

In nearly all Norwegian lakes where sanitary effluents and industrial point sources have been the dominant pollution load, the treatment of effluents by chemical precipitation has had a remarkable effect in improving the water quality. However, in lakes where runoff from agriculture has been the main pollution source, we have not experienced significant water quality improvement (Berge et al

2001). This means that the measures taken against agricultural pollution have not had any detectable effects in the recipients, while the measures to combat domestic sewage pollution (i.e. usually chemical treatment) have resulted in significant water quality improvement.

In most Norwegian sewage treatment plants, the chemical precipitation is very efficient with respect to P-removal, often up to 98% efficiency. The few pure biological sewage treatment plants reduce the P-load by only 25-30 %. Installing biological treatment at the treatment facilities will not have detectable effects in most of the recipients. Only in very small recipients, it can be anticipated to have significant effects. From a hygienic point of view, small recipients create health risks, and the Norwegian policy is to move the discharges to stronger recipients.

9.2 Fjords and coastal waters

As pointed out in section 8.4, the recipients along the Norwegian coastline are all different with regard to topography, water exchange, nutrient load etc. and in general sensitivity to negative effects of organic and nutrient loads. In this context, the coastal area on the Norwegian Skagerrak coast from the Swedish border, in the east, to Lindesnes, in the west, is classified as a problem area with regard to eutrophication (OSPAR). The areas draining into the coastal region from the Swedish border to the lighthouse at Strømtangen and the Inner Oslofjord have been prioritised for measures under the Nitrates and Urban Wastewater Treatment Directives.

In **Figure 20**, the recipients are classified in three main categories: coastal water, open fjords and fjords with restricted water exchange. Appendix B includes a list of outfalls to marine waters. It also illustrates how the treatment is adapted to the general classification of the coastline and the capacity of the local recipients. The following, more specific examples, will serve to illustrate the current Norwegian policy for wastewater treatment and outfalls to marine waters. Many treatment plants became operational during the late 1990s. In many cases, there is therefore not much information available about the positive effects of the treatment on the water quality and the ecosystem of the receiving waters.

9.2.1 Outfalls to coastal waters

Arendal

Up to 2001/2002, the city of Arendal at the Skagerrak coast had a treatment plant based on mechanical treatment, with an outfall at 30 m depth in the coastal waters (**Figure 29**). The load (based on P) is 35.000 PE, but the hydraulic load is much higher. By using an outfall through a diffuser, the plume is usually trapped at 15-20 m depth.

In the outfall area and further offshore, the Norwegian Coastal Current flows to the south-west with a typical speed of 0.25-0.5 m/s, corresponding to a volume transport of 200-300 000 m^3/s. This creates a high capacity for receiving wastewater without adverse effects on oxygen conditions or eutrophication effects. This was shown in a study from 1992-94, where the oxygen concentration in the water mass at the outfall site was higher than 6 mlO_2/l and classified as 'Very Good' according to the Norwegian classification system for marine waters. No adverse effects on bottom fauna were found (Jacobsen et al., 1996a).

The city has recently (winter 2001/2002) upgraded the treatment plant to chemical precipitation. In the untreated sewage, typical concentrations of P are 1.5-3 mgP/l, and of COD 160-300 mg/l. The removal efficiency so far is P >92% and COD >70%. A new study of the recipient is planned for 2002-2003 in order to provide an updated description of the situation in the area, but no changes related to oxygen are foreseen.

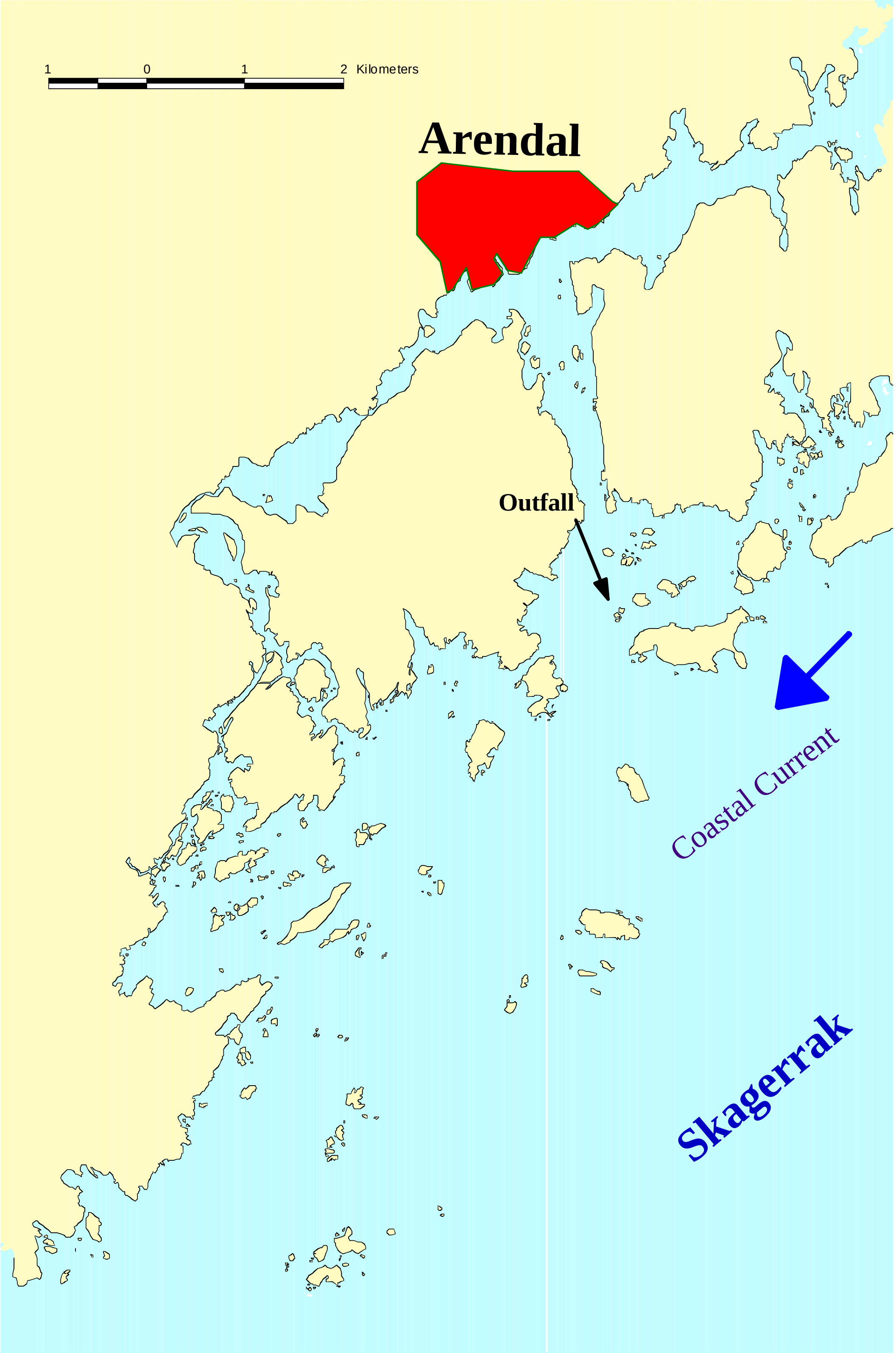

Figure 29. The coast of Arendal, with the wastewater outfall indicated.

The Haastein fjord, west of Stavanger:
In 1991/92 the city of Stavanger constracted a treatment plant based on chemical precipitation with an outfall at 80 m depth in the coastal water of Haasteinfjord (**Figure 29**). The load is 152 000 PE and the plume is trapped at time-varying levels between the surface and 30 m depth. The recipient is classified as a less sensitive under the Urban Waste Water Treatment Directive.

In this area the Norwegian Coastal Current northwards, with a typical speed of 0.15-0.2 m/s. The water masses have a high capacity for receiving wastewater without adverse effects on oxygen conditions or eutrophication effects (Eidnes et al 1987, Eidnes 1987). This was confirmed in a study from 1995, where the oxygen concentration in the water mass was higher than 4.5 mlO_2/l and therefore classified as 'Very Good' according to the Norwegian classification system for marine waters (**Figure 31**). No adverse effects were found on the hard bottom fauna (Bokn et al., 1996).

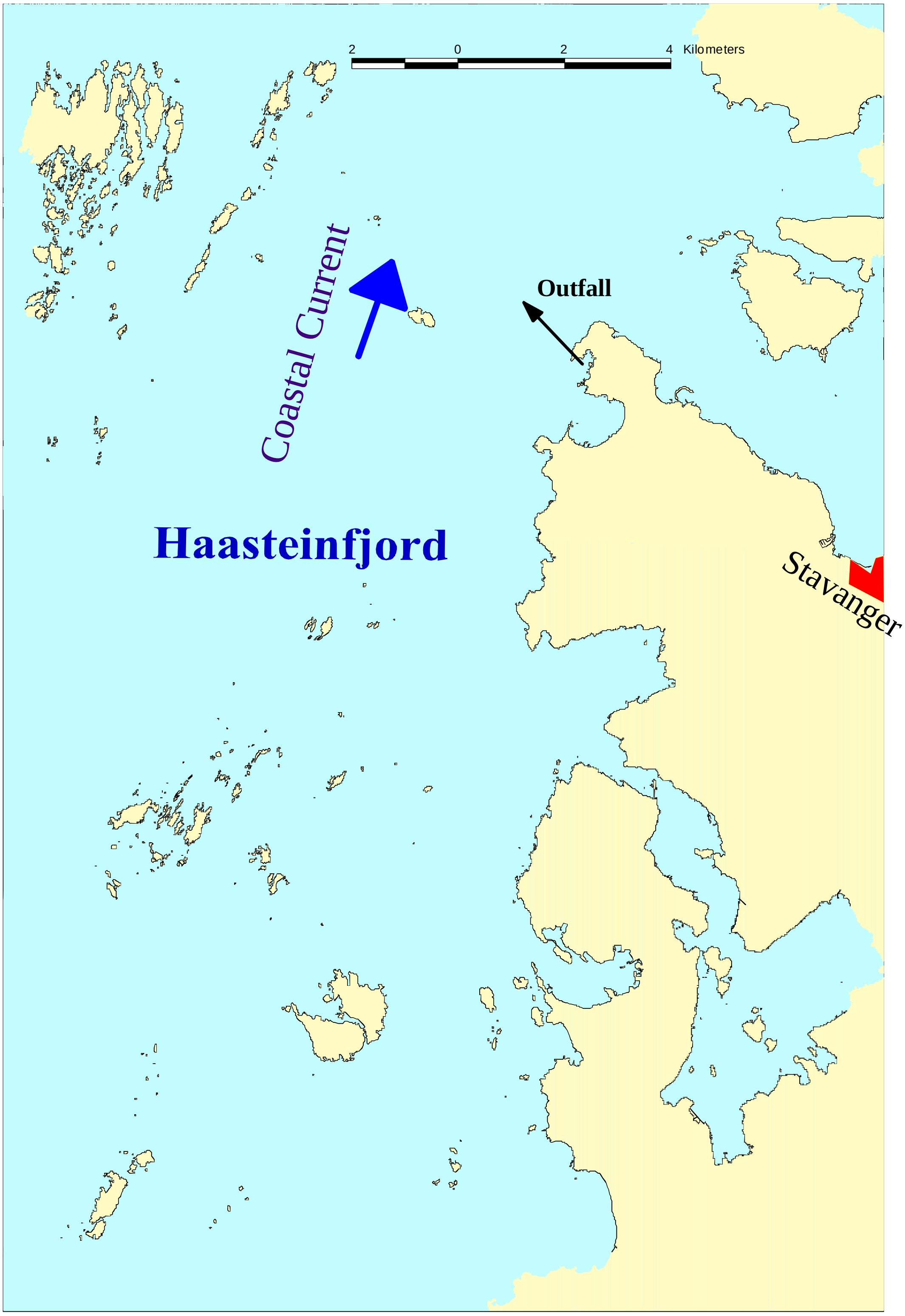

Figure 30. The Haasteinfjord, Stavanger with the wastewater outfall indicated.

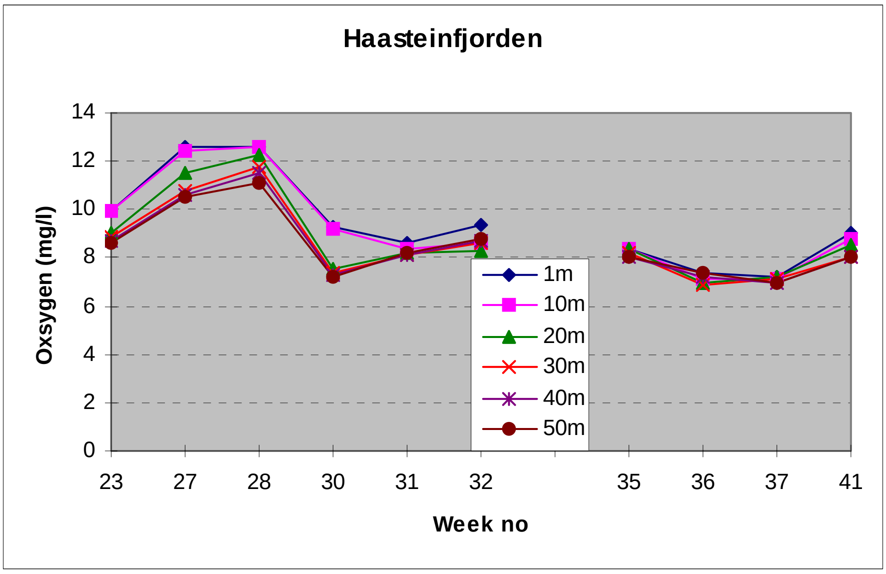

Figure 31. Oxygen concentration between surface and 50 m depth in the Haasteinfjord June-October 1995 (data from Bokn et al. 1996).

9.2.2 Outfalls to open fjords

This section shows outfalls to recipients inside the rapid flowing coastal water, but still to open and wide recipients with high water exchange with the coastal water.

The Kristiansandsfjord:
The Kristiansandsfjord is an open and deep fjord with free connection to Skagerrak waters. The innermost and relatively shallow bays near the city of Kristiansand (**Figure 32**) have been polluted by contaminants from industrial sources and municipal effluents. The main problems have been related to metals and organochlorine contaminants, but the effects from inputs of nutrients and organic matter were also significant. As from mid 1970s, actions have been taken to reduce the organic discharges from municipal sewage and industry. This includes chemical treatment with removal of phosphorus. In addition, the discharges have been transferred from the inner bays to more open parts of the fjord with high water renewal. Furthermore, the outfall points have been submerged (30-50 m) to obtain high dilution and trapping of the effluent water in intermediate water layers.

These measures have reduced the organic load to the fjord considerably. Follow-up studies of benthic biota in the vicinity of the Korsvik treatment plant (approx. 15.000 PE), 15 years after it became operational in 1978 showed that soft-bottom fauna and shallow-water organisms close to the outfall were only slightly or not at all affected (Figure 33, Oug et al., 1994). During the 1980s and early 1990s, when the wastewater treatment plants came fully into effect, the diversity of species communities have increased considerably in the inner bays and most affected parts of the fjord.

No oxygen problems have been found in the Vesterhavn near the Korsvik discharge (**Figure 33**).

Figure 32. The Kristiansand fjord with outfalls of wastewater indicated.

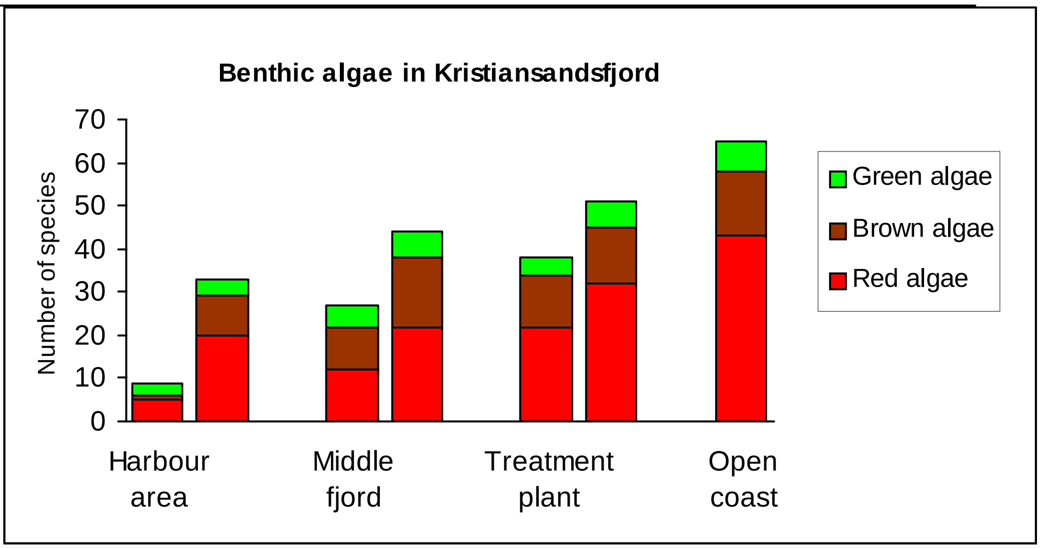

Figure 33. Distribution of shallow-water benthic algae in the Kristiansandsfjord and close to the Korsvik treatment plant in 1982 (left columns) and 1992 (right columns) and open coast. Data from Oug et al. (1994).

9.2.3 Fjords with shallow sills and restricted water exchange

The three examples below illustrate the recipient-oriented strategy in the most sensitive recipients.

Inner Oslofjord:
The Oslofjord extends approximately 90 km into the mainland from Skagerrak. A 20 m deep sill at Drøbak separates the inner and outer part of the fjord. The inner Oslofjord is further separated into two main basins with maximum depth of 160 m. The deep water in the basins is exchanged by annual or less frequent inflow of water from the intermediate water in the outer fjord. Oxygen depletion in the deep water occurs during stagnant periods in some of the basins. The city of Oslo is located at the northern end of the fjord, and discharge of wastewater from the city contributes significantly to the loads of organic matter and nutrients to the fjord.

The inner Oslofjord, in particular the areas close to the city of Oslo became increasingly polluted from waste-water discharges during the 1950s and 1960s. Already in the 1960s, when measures for counteracting the pollution were planned, it was realised that eutrophication, caused by plant nutrients, represented the most severe effect of the wastewater discharge. It was concluded from experimental studies that the secondary organic load arising from nutrients were five to ten times higher than the primary load of organic matter. Phosphorus was considered to be the limiting nutrient, and, hence, P-removal by chemical precipitation was chosen as the most appropriate measure to reduce the pollution. Between 1985 and 1998 the phosphorus inputs from landbased anthropogenic sources were reduced by about 70% (**Figure 35**).

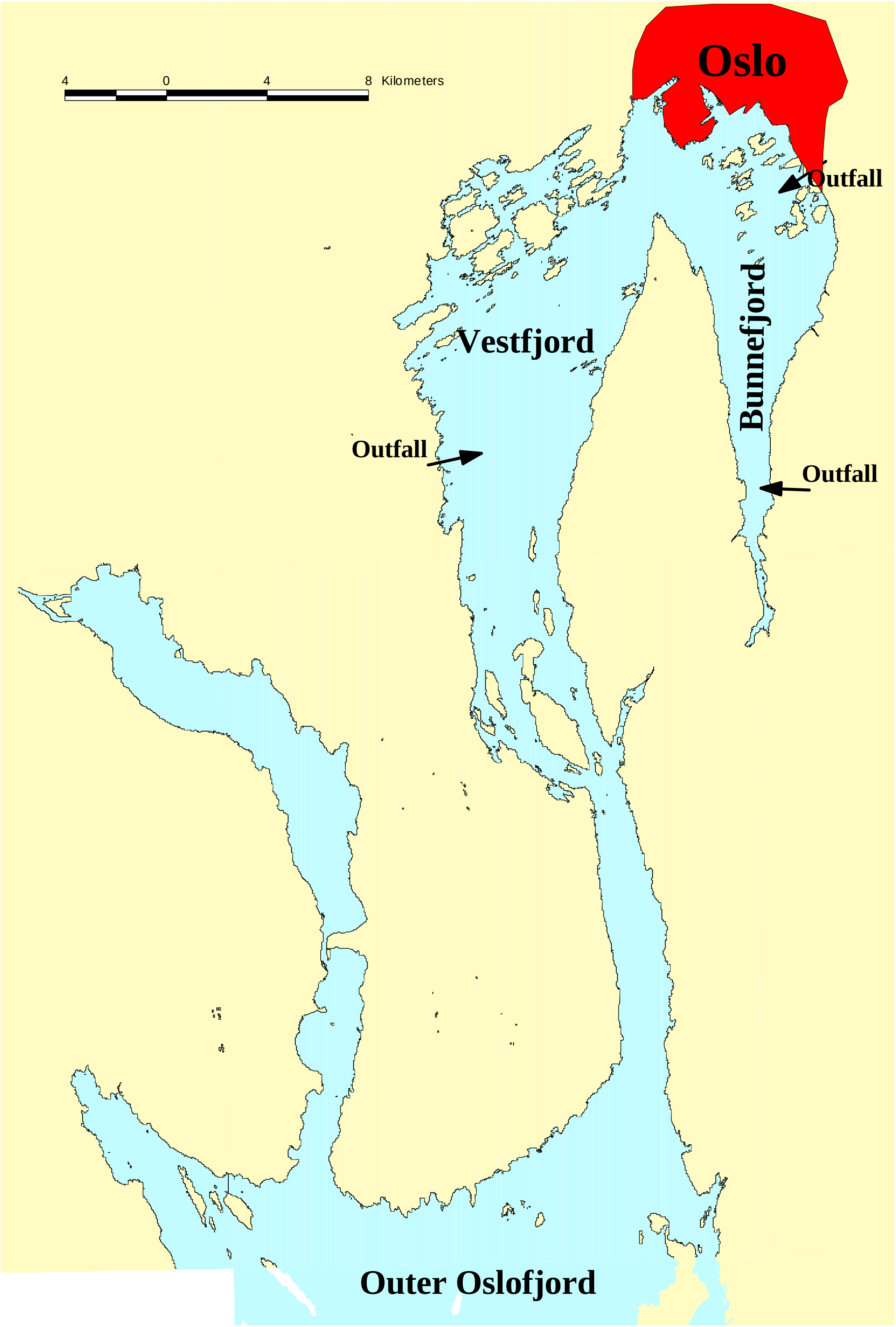

Figure 34. Inner Oslofjord with main wastewater outfalls indicated.

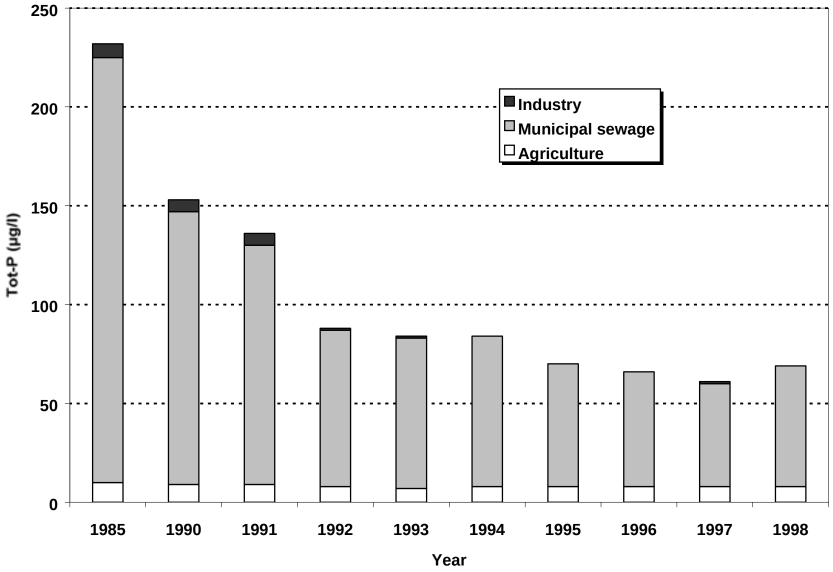

Figure 35. Input of phosphorus to inner Oslofjord from industry, municipal sewage and agriculture in 1985 and 1990-98 (from Borgvang and Tjomsland, 2000).

Since 1980 there has been a substantial improvement of surface water quality, with significant reduction of plankton density in summer (**Figure 36**). In the deep water the decreasing oxygen trend was reversed after the main treatment plant came into operation in 1982 (**Figure 37**). Problems with deoxygenation still remains both in the Vestfjord and the Bunnefjord. This situation is further complicated by variations in the (a)periodic deep-water exchange, and the oxygen content of the deep water flowing in from the outer Oslofjord. The oxygen content of the inflowing water masses has shown a steady decline over the last 70 years. This seems to be a result of the eutrophication of the inner Skagerrak waters.

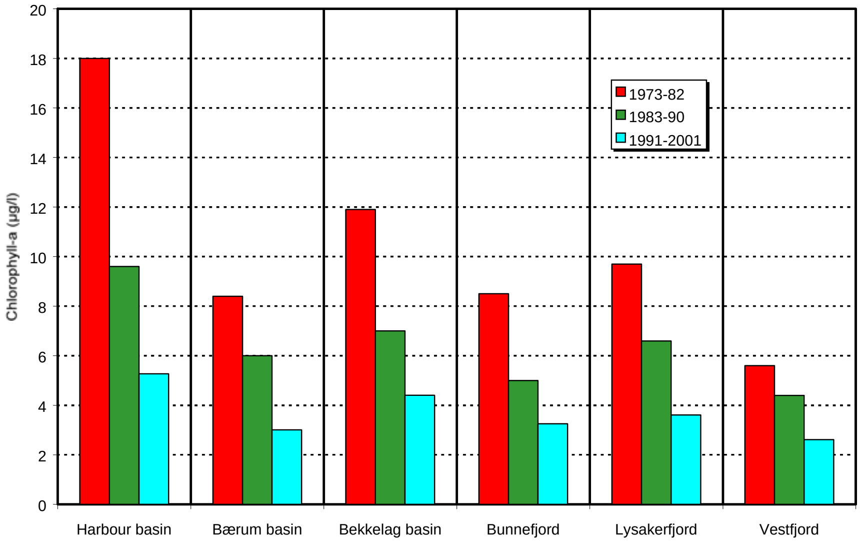

Figure 36 Average phytoplankton density (as chlorophyll-a) in surface water in June-August calculated for three periods (1973-82, 1983-90 and 1991-2001) at different locations in the Oslofjord. (Jan Magnusson, NIVA, pers. communic.).

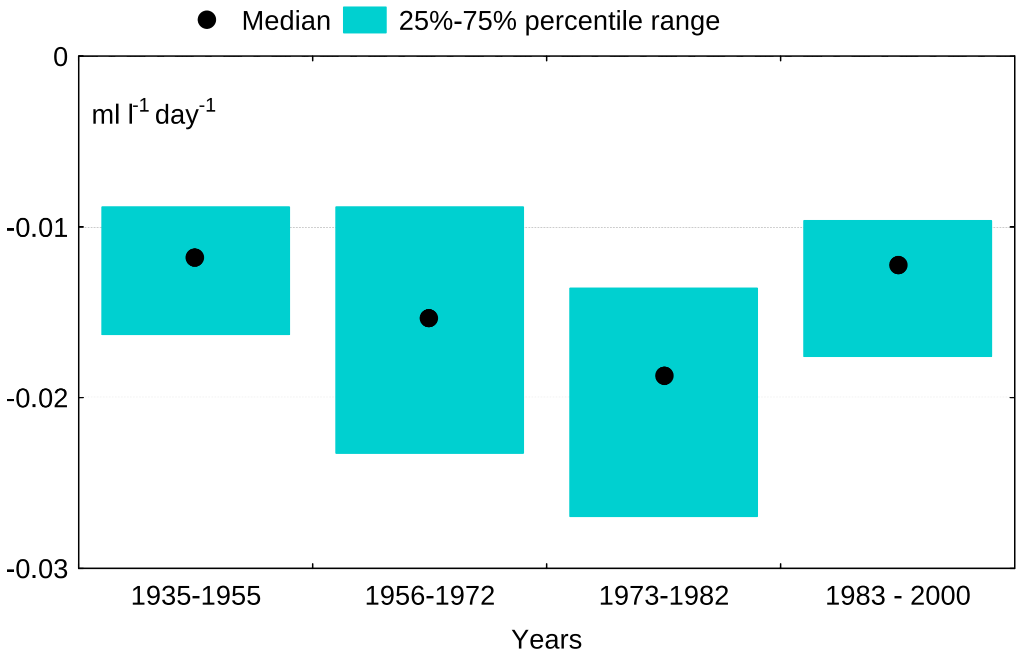

Figure 37. Volume-averaged oxygen consumption rates below 72.5 m depth in the Vestfjord. Data suggests that the oxygen consumption increased by 50-60% from 1933-55 to 1973-82. After 1982 when the main treatment plant came into operation a similar reduction in oxygen consumption took place (from Magnusson et al. 2001).

The major treatment plants in the Oslo area was recently upgraded with biological treatment, primarily to reduce the discharge of N. This has also had the effect to further reduce the load of organic matter and ammonia, which contribute to the oxygen consumption in the receiving waters. Ecological modelling has been used to calculate the effect of the pollution abatement measures and to identify the optimal discharge point.

The Grenland fjords

The Grenland fjords are situated south of the cities of Porsgrunn and Skien. (**Figure 3** and **Figure 38**). The Frierfjord is the innermost fjord, with a sill of 23 m and a maximum depth of 98 m. The average freshwater inflow from Skien river is 250 m^3/s. Frierfjord has received for wastewater from the cities and industrial effluents from paper industry and production of fertilisers and other chemical production over the last 40-50 years. The bottom water is stagnant for longer periods and is probably naturally anoxic due to the reduced water exchange. Adverse effects due to heavy discharges of nutrients and organic matter have been documented since monitoring studies started in 1974. The fjord environment was then characterised by dense blooms of planktonic algae, excessive growth of benthic green algae in intertidal areas, and hydrogen sulphide in the water masses below 40 m. During the following 25 years the discharges of nutrients and organic matter were considerably reduced, for nitrogen and phosphorus respectively by 50% and 80-85%. The wastewater from a population of approx. 80.000 is treated by chemical precipitation. The figures for reduction of organic matter are uncertain, but could be in the order of 60% from the population and even higher from the industry (Molvær 2001).

After these reductions of the pollution load, lower nutrient concentrations, reduced plankton biomass (chlorophyll) and improved secchi depth have been documented for the surface layer of the whole fjord area (**Table 7**)

In the basin water of the Frierfjord the oxygen consumption rate has has been reduced to about half of the consumption in the 1970s (**Figure 39**). Compared with the situation at the beginning of the 1970s, the volume of the periodic anoxic water mass had been reduced by 70% (**Figure 40**).

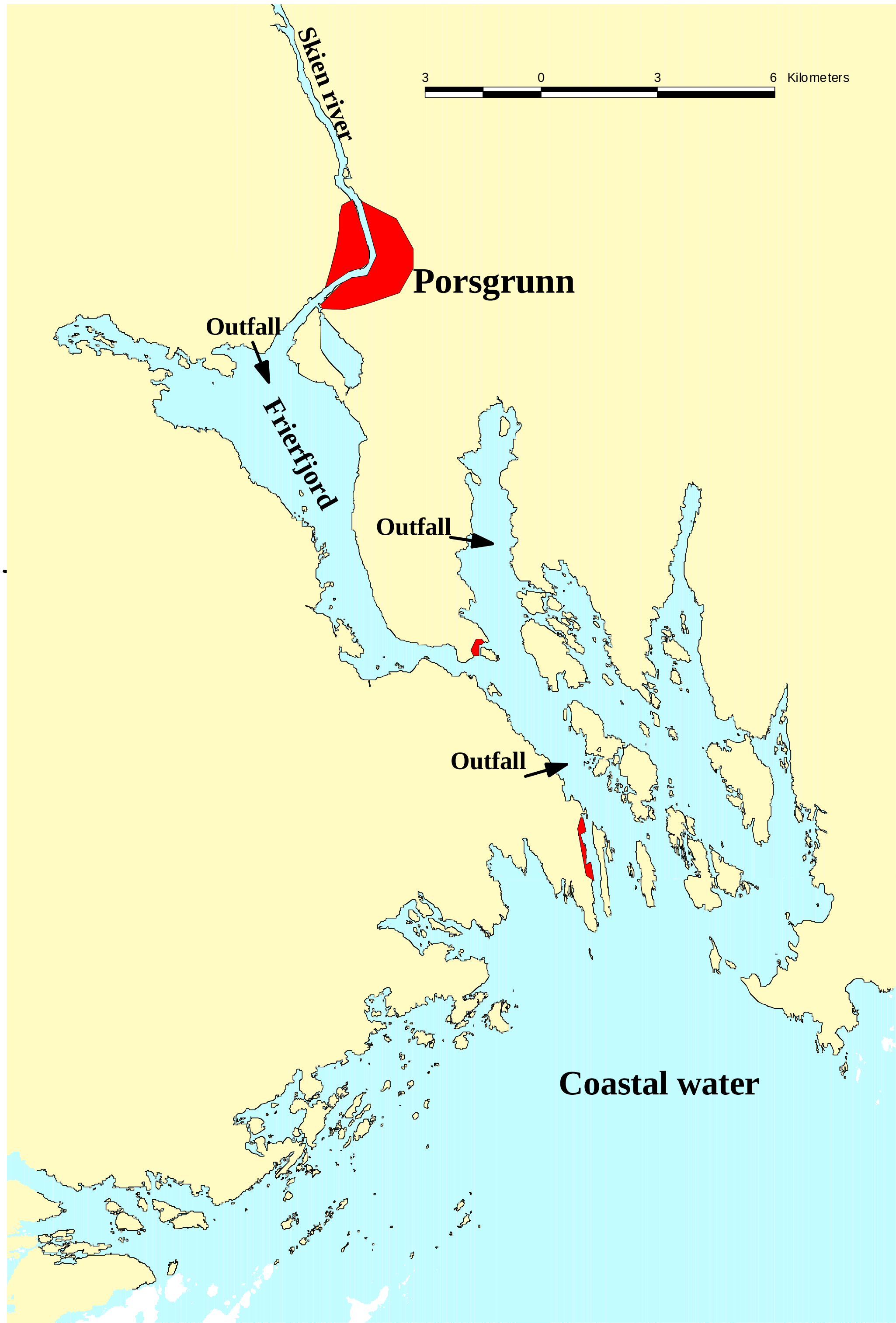

Figure 38. The Grenland fjords with main wastewater outfalls indicated.

Table 7. Classification of the water quality (as medians) in the surface layer of the Grenland fjords during the summer of 1988-89 and 1996-97 (classes are shown in roman characters). Asterisks (*) after the values for 1996-97 show that the value is statistically significantly different from the corresponding value for 1988-89 (after Molvær 1999).

	Period	Frierfjord	Langesundsfjord	Håøyfjord	Langesund bay
Total nitrogen	1988-89	852 µgN/l (V)	560 µgN/l (IV)	430 µgN/l (III)	299 µgN/l (II)
	1996-97	635 µgN/l (IV)***	397 µgN/l (III) ***	255 µgN/l (I-II) ***	210 µgN/l (I) ***
Total phosphorus	1988-89	14 µgP/l (III)	13 µgP/l (II)	15 µgP/l (II-III)	12 µgP/l (I-II)
	1996-97	11 µgP/l (II)*	9.5 µgP/l (I-II) ***	9 µgP/l (I-II) ***	7 µgP/l (I) ***
Chlorophyll a	1988-89	2.9 µg/l (II)	3.9 µg/l (III)	3.9 µg/l (III)	1.4 µg/l (I)
	1996-97	4.6 µg/l (III)	3.0 µg/l (II) ***	2.0 µg/l (I-II) ***	1.0 µg/l (I)
Secchidepth	1988-89	2.9 m (II-III)	3.5 m (II-III)	3.8 m (II-III)	7.5 m (I-II)
	1996-97	4.1 m (I-II) ***	5.0 m (I-II) ***	5.8 m (I) ***	8.5 m (I)

***) $p<0.05$: Lower concentration or larger secchi depth than for the period 1988-89
*) $p<0.1$ but $p>0.05$

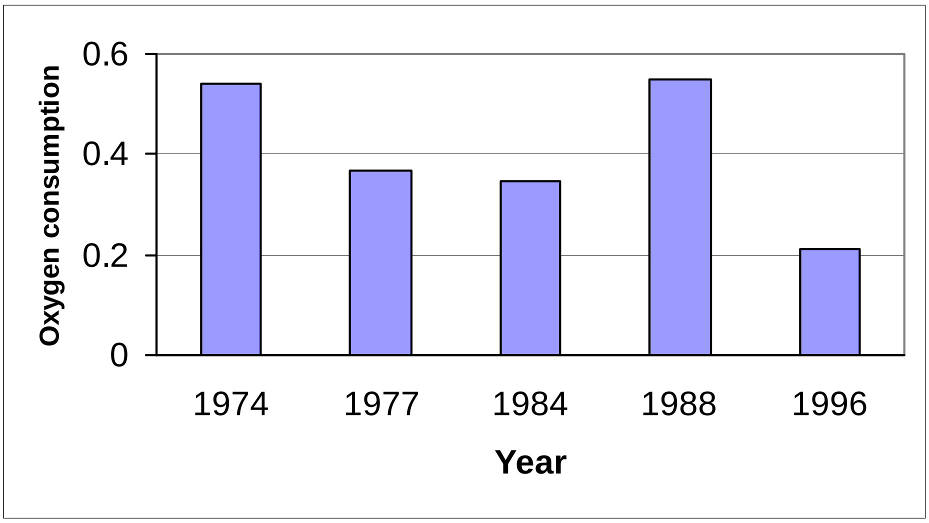

Figure 39. Average oxygen consumption (ml O_2/ l / month) in the deep water (60-100 m) of the Frierfjord after major water renewals. From Molvær (2001).

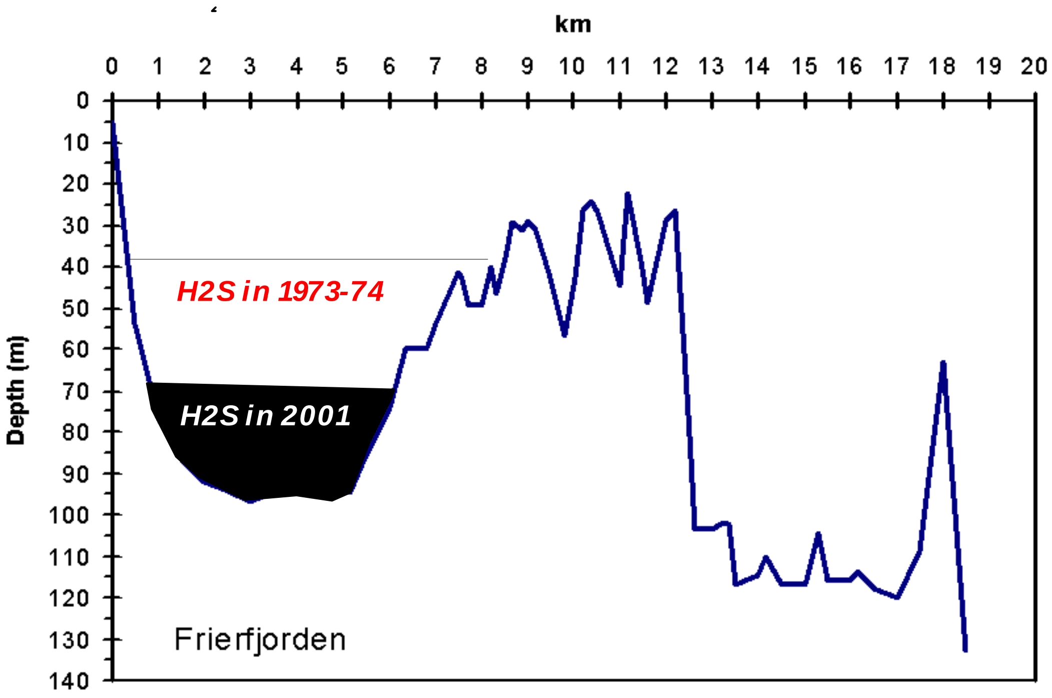

Figure 40. At the end of a period of stagnant basin water in 1974, there was hydrogen sulphide in the whole water body below 40 m depth. By the end of 2000 the basin water had been stagnant for nearly 5 years, the longest period without deep-water renewals since the monitoring started in 1974. Hydrogen sulfide was detected below 70-75 m depth.

Flekkefjord

Flekkefjord is situated west of Kristiansand (**Figure 3** and **Figure 41**). The area is characterised as a less sensitive area under the Urban Waste Water Directive. The fjord system consists of a series of basins with shallow sills and restricted water exchange (**Figure 41**). Recipient studies in 1973-74 (Kolstad et al., 1976) and in 1986-87 (Magnusson et al. 1988) documented serious pollution problems in the fjord system, especially related to low oxygen concentration and presence of hydrogen sulphide in the Loga, the Grisefjord and Tjørsvågsbukt. In 1993 the discharges of municipal wastewater to the Grisefjord and Tjørsvågsbukt were transferred to the Lafjord chemical precipitation plant. The present load is 6440 PE. The wastewater is discharged at 36 m depth and the plume of diluted sewage is trapped between 10 and 25 m depth with a dilution of 20-50x. However, it is not known to which extent this changed the total nutrient and organic load to the surface layer of the for four basins have changed as a result of this transfer. The most recent study was carried out in 1994-95 (Jacobsen et al. 1996b). Even though the biological systems need more than one year to adapt to the altered load, the study shows some relevant results:

Compared to the 1986-87 data, the <u>summer</u> nutrient concentrations in the surface layer in 1994-95 (n=3) showed an unclear picture, with lower concentration of total phosphorus and phosphate in the Grisefjord and a slight increase in the Tjørsvågbukt and Lafjord. The picture was reversed for total nitrogen, while nitrate and ammonium showed unchanged concentrations in the Lafjord.

The secchi depth had improved in the whole area, both summer and winter (**Table 8**).

There are no <u>nutrient winter data</u> available for 1986/87, but data for 1994-95 show low phosphorus concentrations over the whole area (**Table 9**), probably from a combination of reduced load and trapping of the outfall 10-15 m below the surface. The nitrogen concentrations are higher and are explained as a result of inputs from freshwater runoff.

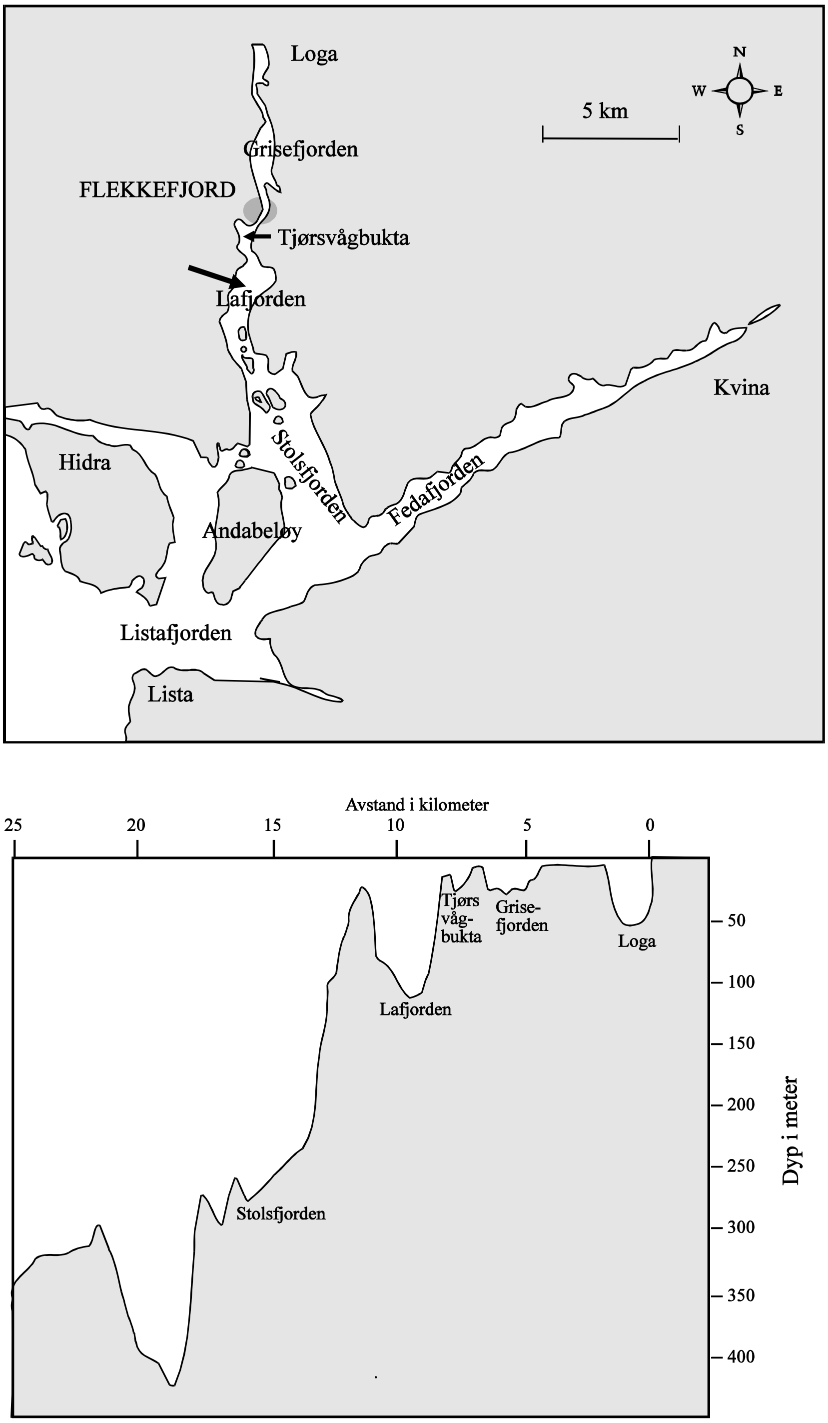

Figure 41. The fjords of Flekkefjord, including the bottom profile. The Lafjord outfall is indicated by an arrow (upper Figure)

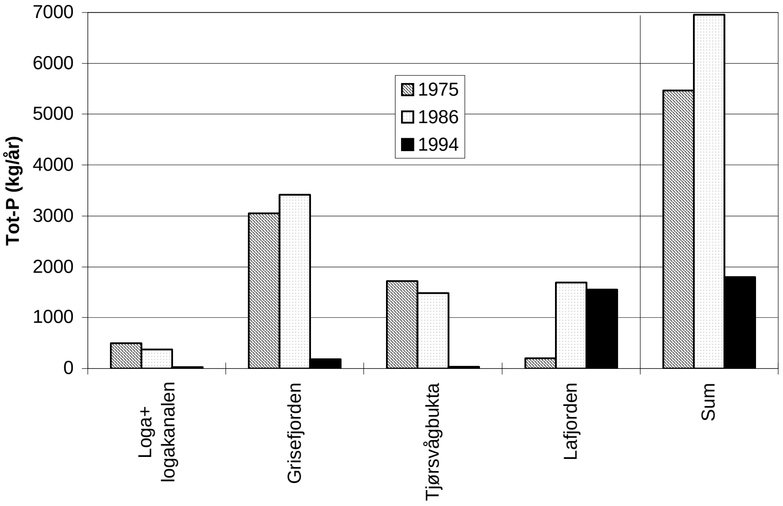

Figure 42. Landbased phosphorus load (kg/year) to the four fjord basins in 1975, 1986 and 1994.

Table 8. *Average secchi depth (meters) in June-September and October -January from the studies in 1986-87 and 1994-95. The Norwegian classification for summer conditions is shown in roman numbers: I = Good, II= Less god, III= Poor, IV= Bad, V= Very bad.*

	June-September				October-January	
Area	1986/87		**1994/95**		1986/87	**1994/95**
Grisefjord	4,3	IV	**5,2**	**III**	4,1	**7,7**
Tjørsvågbukt	6,2	II (III)	**7,0**	**II**	10,5	**14,7**
Lafjord	6,9	II	**7,8**	**I**	10,0	**13,8**

Table 9. *Average nutrient concentrations in the surface layer October 1994-January 1995. The Norwegian classification is shown in roman characters: I = Good, II= Less god, III= Poor, IV= Bad, V= Very bad.*

Winter 94/95	PO_4	Class	Tot-P	Class	NH_4	Class	NO_3	Class	Tot-N	Class	Number obs.
	µg P/l		µg P/l		µg N/l		µg N/l		µg N/l		
Grisefjord	1.3	I	5.8	I	33	II	305	IV	508	III	4
Tjørsvågbukt	5.8	I	13.3	I	37	II	224	III	426	III	4
Lafjord	6.5	I	13.3	I	38.5	II	201	III	379	III	4

When applying the model FjordEnvironment (see section 8.4) on the Lafjord, we find an average residence time of 6.5 days for the water mass above the sill depth (20 m). In 1995-96 the average secchi depth in summer was 7.8 meters, indicating that most of the biomass from the primary production was located between the surface and 15 m depth. This demonstrates that the sinking organic load from the primary production to a large extent is flushed out of the fjord and to the wider and deeper Stolsfjord before it reaches the more stagnant and sensitive basin water of Lafjord.

In 1986-87 the Lafjord experienced periods with hydrogen sulphide in the basin water, but no such situations were found in 1994-95. In the two inner basins hydrogen sulphide was still observed, but deeper than before and with lower concentration.

9.2.4 Discussion and recommendation

The Norwegian policy for discharges of municipal wastewater to marine waters is based on two main principles:

1. Local and regional differences in marine recipients and their varying capacity to receive wastewater discharges (nutrients and organic matter) without any adverse effects on the marine environment: The Norwegian coastline shows a wide variety of marine recipients, from open rapid flowing coastal waters to fjords with shallow and narrow sills and very restricted water exchange. The water exchange between coastal water and the fjords increases from south to north, as the tidal amplitude increases 10-fold and meteorological conditions are more important.

2. The need for reduction of organic load from primary production: Municipal sewage contains high concentrations of nutrients. In marine recipients the organic load from the primary production based on these nutrients are far larger than the organic load from the wastewater itself. In order to reduce the oxygen consumption due to degradation of organic matter in the fjord basins, it is therefore necessary to reduce the organic load from the primary production. Chemical precipitation has been chosen as the general wastewater treatment method. With this treatment, removal of 60-70% of the organic and 90-95% of phosphorus is normally achieved. An important additional advantage gained from this treatment is the high removal efficiency (98-99.9%) for bacteria and viruses, and a considerable (70-80%) removal of metals and organochlorine compounds.

The combination of these two principles is the foundation for a recipient-orientated approach, (see Appendix B for more details):

A number of wastewater outfalls to open coastal waters are situated along the coast of Skagerrak and the coast of west Norway. On the Skagerrak coast (identified as sensitive area under the Urban Waste Water Treatment Directive) chemical precipitation is standard wastewater treatment. The west coast up to northern Norway is identified as a less sensitive area. Here the treatment has been chosen according to the size of the outfalls and the recipient capacity. The preferred treatment method therefore has varied from chemical precipitation (Haasteinfjord) to some cases of no treatment in northern Norway.

On the Skagerrak coast chemical precipitation is standard treatment also for outfalls to open fjords with high water exchange. The west coast representsa less sensitive area and the recipients are mainly coastal waters and open fjords. Chemical (see Aalesund and Stjørdal, Verdal and Steinkjer in the inner parts of the Trondheimsfjord) or mechanical treatment has been chosen depending on to the size of the outfall and the recipient capacity. Numerous studies have shown that with wastewater discharges to recipients with high water exchange the organic matter in the sewage creates no adverse effects on oxygen conditions or bottom fauna.

Measures to reduce the organic load into marine recipient are most essential in fjords with shallow or narrow sills and with restricted bottom water renewal. At such locations, the primary measure to reduce the oxygen consumption in the deep water should be removal of plant nutrients in order to reduce the secondary organic load originating from the production of algae in the photic layer. Depending on the local conditions, including the supply of freshwater and nutrient inputs from other sources, chemical precipitation methods for removal of phosphorus and organic matter, and possibly nitrogen is required. Additional biological treatment of chemically treated wastewater may be required in the most sensitive areas, but so far no such cases have been identified.

Many treatment plants have become operational during the late 1990s. In many cases. Therefore, there is not as yet much concrete information about the effects of the treatment on the water quality and the ecosystem of the receiving waters. However, studies from both large outfalls to fjords with restricted water exchange (Inner Oslofjord), more open fjords (such as the Kristiansandsfjord) and coastal water (such as Arendal and Haasteinfjord) show that this strategy is effective.

We see no need for a change in the recipient-orientated strategy as implementd to date. A number of recipient studies are in the final part (like around the main outfalls to sensitive area in outer Oslofjord - and the Trondheimsfjord) or being planned (like the studies related to the new Arendal outfall to the coastal water and the four outfalls to the fjord area around Bergen). An evaluation of the need for upgrading of treatment for these outfalls should follow the reports from these and otheer studies. The Mandal outfall (mechanical treatment) to the sensitive area must also be considered for upgrading to chemical precipitation. The outfalls with no treatment or fairly coarse mechanical treatment in Northern Norway are also under consideration for improved treatment.

We therefore suggest a continuation of this strategy, which also complies with the design for monitoring and reporting which has been outlined in the Council Directive concerning urban waste water treatment.

10. References

Andersson, L., 1996. Trends in nutrient and oxygen concentrations in the Skagerrak-Kattegat. *Journal of Sea Research* 35 (1-3): 63-71 (1996).

ANON, 1996. Ytre Oslofjord. Eutrofitilstand, utvikling og forventede effekter av reduserte tilførsler av næringssalter. Rapport fra ekspertgruppe for vurdering av eutrofiforhold i fjorder og kystfarvann. *State Pollution Control Authority* (SFT), Norway. 147 pp. [In Norwegian]

ANON, 1997. The Norwegian North Sea Coastal Water. Eutrophication – status and trends. Report from expert group for evaluation of eutrophication in fjords and coastal waters. *State Pollution Control Authority* (SFT), Norway. 90 pp.

Aure, J. and Stigebrandt, A., 1989a. Fiskeoppdrett og fjorder. En konsekvensanalse av miljøbelastning for 30 fjorder i Møre og Romsdal. Rapport FO 8803 Havforskningsinstituttet, Bergen. 106 pp.+Appendix. [In Norwegian].

Aure, J. and Stigebrandt, A., 1989b. On the influence of topographic factor upon the oxygen consumption rate in sill basins of fjords. *Estuarine, Coastal and Shelf Science, 28, 59-69.*

Aure, J., D. Danielssen & R. Sætre 1996. Assessment of eutrophication in Skagerrak coastal waters using oxygen consumption in fjordic basins. ICES J. mar. Sci. 53: 589-595.

Berge, D. 1987: Phosphorus loading and response in shallow and moderately shallow lakes. How to assess acceptable trophic degree and acceptable phosphorus loading in lakes with average depth from 1.5-15 m., NIVA report O-85110, 44 pages. [In Norwegian]

Berge, D. 1990: FOSRES - a phosphorus loading model for shallow Lakes. *Verh. Int. Verein Limnol. 24:218-223.*

Berge, D., S. Rognerud and M. Johannessen, 1980: Further Development of Phosphorus Loading Models for Large Stratified Lakes. Norwegian Institute for Water Research, Yearbook 1979: 39-42. [In Norwegian]

Bokn, T., Johnsen, T.M., Knutzen, J., Lømsland, E., Moy, F., Nygaard, K. and Rygg, B., 1996. Resipientundersøkelser 1995 i sjøområder rundt Stavangerhalvøya. NIVA-rapport nr. 3493-96. 127 pp. [In Norwegian]

Borgvang, S. and Tjomsland, T., 2001. Tilførsler av næringssalter til Norges kystområder, beregnet med tilførselsmodellen TEOTIL. NIVA-rapport nr. 4343-2001. 40 pp. [In Norwegian]

Bratli, J.L., Holtan, H. and Åstebøl, S.O., 1995. Miljømål for vannforekomstene. Tilførselsberegning. SFT-veiledning 95:02. TA-1139/1995. 70 pp. [In Norwegian]

Bratli, J.L., D. Berge, E. A. Lindstrøm, T. Bækken, and K. Kjellberg, 1998. Resipient surveillance in River Begna, River Storelva, and lake Tyrifjord 1997. NIVA-Report, Lno. 3872-98., 53 pp. [In Norwegian]

Dahl, E. 1998. Undersøkelser av næringssaltforhold og oksygenforhold i Groosefjorden, Grimstad kommune 1998. Institute for Marine Research, Flødevigen. Mimeo. 12 pp. ISBN 82-577-3454-3.

Eidnes, G. 1987. Sentralrenseanlegg Nord-Jæren. Hydrofysisk vurdering av Tungeflua som utslippslokalitet. NHL-rapport STF60 F87105. 50 pp. [In Norwegian]

Eidnes,G., Molvær, J. og Simensen, T., 1987. Sentralrenseanlegg Nord-Jæren. Håsteinfjorden som resipient, sammenlignet med indre og ytre Byfjord. NHL-rapport STF60 F87051. 54 pp. [In Norwegian]

Erga, S.R., E. Oug, J. Knutzen & J. Magnusson 1990. Eutrofitilstand for norske fjorder og kystfarvann med tilgrensende havområder. Statlig prog. forurensningsovervåk. 391/90 (NIVA report 2370). SFT/NIVA. Oslo. 131 pp.

Forum Skagerrak 2001. The Skagerrak, environmental state and monitoring prospects. Eds. Karlson, B., B. Håkansson & B. Sjöberg. Interreg. IIC, Göteborg. 118 pp.

EEA 2001. Europe's Environment - The Dobris Assessment. European Environment Agency.

Holtan, G., Berge, D., Holtan, H. and Hopen, T. 1997. Paris Convention. Annual report on direct and riverine inputs to Norwegian coastal waters during the year 1996. A. Principles, results and discussion. B. Data report. Norwegian Pollution Control Authority report 715/97. 138 pp.

Jacobsen, T., Oug, E. and Magnusson, J., 1996. Vannkvalitet i kystområdene i Arendal kommune 1992-1994. NIVA-rapport 3378-95. 100 pp. [In Norwegian]

Jacobsen, T., Golmen, L., Nygaard, K. and Moy, F., 1996. Resipientundersøkelse i fjordene ved Flekkefjord 1994-95. NIVA-rapport 3456-96. 53 pp.+Appendix. [In Norwegian]

Kjellberg, G., O. Hegge, and J. E. Løvik, 2001. Monitoring of Lake Mjøsa with tributaries in year 2000., NIVA-Report, Lnr. 4364-2001, 129 pp. ISBN 82-577-4001-2. [In Norwegian]

Kolstad, S., Bokn, T., Kirkerud, L., Molvær, J. and Rygg, B., 1976. Resipientundersøkelse av fjordsystemet i Flekkefjordregionen. NIVA-rapport 123/72. Oslo.

Larsson, U., 1988. Kväve och fosfor som biomassebegränsande ämnen i havet. VATTEN, 44:19-28.

Magnusson, J., Næs, K. and Tangen, K., 1988. Resipientundersøkelser av fjordområdet ved Flekkefjord 1986/87. Vannkvalitet, planteplankton, krom i sedimenter og blåskjell. NIVA-rapport 2071-88. 102 pp. [In Norwegian]

Magnusson, J., Berge, J.A., Bjerkeng, B., Bokn, T., Gjøsæter, J., Johmnsen, T., Lømsland, E.R., Schram, T.A. and Solli, A. 2001: Overvåking av forurensningssituasjonen i indre Oslofjord 2000. Norwegian Institute for Water Research, Report 4387. 90 pp. [In Norwegian]

Martinsen, T. 2001. Environmental studies in Lake Øyeren 1994-2000: Water Quality., Report from ANØ, In press. [In Norwegian]

Midttun 1993 :Patogener i kommunalt avløpsvann. SFT-rapport 93:25. [In Norwegian]

Ministry of the Environment Env.1993. Miljøverndepartementet 1993. Stortingsmelding nr 13 (1992-1993). [In Norwegian]

Molvær, J., 1999. Grenlandsfjordene 1994-97. Undersøkelser av vannkjemiske forhold og vannutskiftning. Statlig program for forurensningsovervåking rapport nr. 756-99. NIVA-rapport nr. 3960-98. Oslo. 47 pp. [In Norwegian]

Molvær, J. 2001. Overvåking av Grenlandsfjordene 2000. Oksygenforhold og vannutskiftning NIVA-rapport 4374-2001. [in Norwegian].

Mork, K. 1997: Utslepp og rensing av avløpsvatn. Datakvalitet og berekningsmåter. Statistics Norway 97/62, 64 pp. [In Norwegian]

OECD 1982: Eutrophication of waters: Monitoring, assessment and control. OECD EUTROPHICATION PROGRAMME - FINAL REPORT., Paris, France. 155 pp.

Oredalen, T., B. Faafeng, P. Brettum, J.E. Løvik 2000. Monitoring of Lake Gjersjøen 1972-99 and the results from the 1999 season., NIVA-Report, Lnr. 4274-2000., 56 pp., ISBN 82-577-3909-2. [In Norwegian]

OSPAR 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions, London. 132 pp.

Oug, E., T. Jacobsen & F. Moy 1994. Overvåking av Kristiansandsfjorden 1992-93. Hardbunnsorganismer og bløtbunnsfauna ved Odderøya, i Vesterhavn og i Korsvikfjorden. Norwegian Institute for water Research, report 3075, 56 pp. [In Norwegian]

Paasche, E. and Erga, S.R., 1988. Phosphorus and nitrogen limitation of phytoplankton in the inner Oslofjord (Norway). Sarsia Vol. 73, 229-243.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963. The influence of organisms on the composition of seawater. In: Hill, M.N. (ed.) The Sea Vol. 2, Interscience: 26-77.

Rognerud, S., D. Berge, and Morten Johannessen, 1979: Surveilances of the Telemark Watercourse. Final Report from the studies during 1975-79., NIVA- report, O-70112, 82 pages. [In Norwegian]

Ryther, J.H. and Dunstan, W.M., 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science, 171:1008-1013.

Sakshaug, E., Andresen, K., Myklestad, S. and Olsen, Y. 1983. Nutrient status of phytoplankton communities in Norwegian waters (marine, brackish and fresh) as revealed by their chemical composition. *Journal of Plankton Research 5(2): 175-199.*

SFT 1995. Environmental Goals for the Water Resources. Guideline 95:01 from State Pollution Control Authority (SFT), Report TA-no.1138/1995., ISBN 82-7655-257-9, 50 pp. [In Norwegian]

SFT 1997: Classification System for Water Quality in Freshwaters. Guideline 97:04 from State Pollution Control Authority (SFT), Report TA-no.1468/1997., ISBN 82-7655-368-0, 31 pp. [In Norwegian]

Statistics Norway 2000. Naturressurser og Miljø 2000. Statistical Analyses, 282 pp. [In Norwegian]

Stigebrandt, A. 2001. FjordEnv – A water quality model for fjords and other inshore waters. Report C40. Earth Sciences Centre. Gøteborg University. 41 pp.

Vollenweider, R.A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication., OECD, Paris, Tech. Rep. DAS/CSI/68., 27, 182 pp.

Vollenweider, R.A., 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol., 33:53-83.

Ødegaard, H. 1992. Norwegain experiences with chemical treatment of raw wastewater. Water Science and Technology Vol. 25, no. 3, pp. 255-264.

Ødegaard, H. and Skrøvseth, A.F. 1997: An evaluation of performance and process stability of different processes for small wastewater treatment plants. Water Science and Technology Vol. 35, no. 6, pp. 119-127.

Appendix A.

Classification of environmental quality in freshwater

The basis for the division of parameters into quality classes is a combination of statistical information about the distribution of the substances in Norwegian watercourses, and knowledge about the substance's effects on the ecology in the water environment.

The table shows the classification of *quality status*. The key parameters are written in italic.

Table: Classification of the quality status for nutrients, organic matter, acidifying components, particles and faecal bacteria.

Effect categories:	**Parameters**	**Quality class**				
		I “Very good”	**II “Good”**	**III “Fair”**	**IV “Bad”**	**V “Very bad”**
Nutrients	*Total phosphorus*, µg P/l	<7	7-11	11-20	20-50	>50
	Chlorophyll a, µg/l	<2	2-4	4-8	8-20	>20
	Secchi, m	>6	4-6	2-4	1-2	<1
	Prim.prod., g C/m^2 y	<25	25-50	50-90	90-150	>150
	Total nitrogen, µg/l	<300	300-400	400-600	600-1200	>1200
Organic matter	*TOC*, mg C/l	<2,5	2,5-3,5	3,5-6,5	6,5-15	>15
	Colour, mg Pt/l	<15	15-25	25-40	40-80	>80
	Oxygen, mg O_2/l	>9	6,4-9	4-6,4	2-4	<2
	Oxygen, %	>80	50-80	30-50	15-30	<15
	Secchi, m	>6	4-6	2-4	1-2	<1
	COD_{Mn}, mg O/l	<2,5	2,5-3,5	3,5-6,5	6,5-15	>15
	Iron, µg Fe/l	<50	50-100	100-300	300-600	>600
	Manganese, µg Mn/l	<20	20-50	50-100	100-150	>150
Acidifying components	*Alkalinity*, mmol/l	>0,2	0,05-0,2	0,01-0,05	<0,01	0,00
	pH	>6,5	6,0-6,5	5,5-6,0	5,0-5,5	<5,0
Particles	*Turbidity*, FTU	<0,5	0,5-1	1-2	2-5	>5
	Susp. matter, mg/l	<1,5	1,5-3	3-5	5-10	>10
	Secchi, m	>6	4-6	2-4	1-2	<1
Faecal bacteria	*Thermotol. coli. bact.*, num./100 ml	<5	5-50	50-200	200-1000	>1000

Appendix B. Overview for marine outfalls

The following table gives an overview for Norwegian marine outfalls, mainly after Nedland (2001). The recipient ar classified as:

1. Coastal water
2. Open fjord or open area with islands and sounds: large water volumes and high water exchange
3. Fjord with restricted water exchange due to sills or other constrictions

Outfalls to sensitive area are shown in grey.

The table gives a general illustration of the recipient-oriented strategy for treatment of municipal wastewater. For sensitive area chemical treatment (Chemical precipitation) is the standard method, but the same treatment is applied west and north of Lindesnes for discharges to recipients which from local studies have been classified as type 3 (see Flekkefjord), type 2 (Aalesund and Stjørdal, Verdal and Steinkjer in inner parts of Trondheimsfjord) and even type 1 (Haasteinfjord near Stavanger).

The Evalutation column shows recommendations regarding the need for upgrading the present treatment of the sewage (to biological, chemical or mechanical treatment):

- OK: no further need
- OK(?): not sufficient information
- Monitoring and evalutation: for consideration after completion of monitoring or baseline studies
- Upgrading: upgrading from no treatment or present level of treatment, for one or several outfalls.

Fjord area	Type of recipient	Municipal ww. Load, PE	Treatment	Evaluation	Comments
Inner Oslofjord: Bekkelaget VEAS Indre Follo	3	 280000 430000 38000	Chemical+ biological	OK	Sensitive area
Fredrikstad	2	64300	Chemical precipitation	OK(?)	Sensitive area
Moss	3	10700	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Drammensfjord	3	38000	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Horten	2	19300	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Holmestrand	2	9000	Chemical precipitation	Monitoring +Evaluation	Sensitive area
TAU, Tønsberg	2	50000	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Vårnes	2-3	7300	Chemical precipitation	Monitoring +Evaluation	Sensitive area

Sandefjord	2	37300	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Larvik	2	24100	Chemical precipitation	OK	Sensitive area
Grenland:					Sensitive area
Knardalstrand	3	43200	Chemical precipitation	Monitoring +Evaluation	
Heistad	2	10300			
Salen	2	9900			
Kragerø	3	10000	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Risør	1	4000	Biological	OK	Sensitive area
Tvedestrand	3	3000	Biological	Monitoring +Evaluation	Sensitive area
Arendal	1	36800	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Grimstad	3	16000[1]	Biological	Monitoring +Evaluation	Sensitive area
Lillesand	2	5400	Chemical precipitation	Monitoring +Evaluation	Sensitive area
Kristiansand:					Sensitive area
Vesterhavn	2	28200	Chemical precipitation	OK(?)	
Korsvik	2	13600			
Bredalsholmen	2	22700			
Høllen	2	6300	Chemical precipitation	OK(?)	Sensitive area
Mandal	1	11500	Biological	OK	Sensitive area
Farsund	2	16400	Mechanical	Monitoring +Evaluation	Less sensitive area
Flekkefjord	3	6400	Chemical precipitation	Monitoring +Evaluation	Less sensitive area
Egersund	1-2	9000	Mechanical	Monitoring +Evaluation	Less sensitive area
Bore, Jæren	1	8800	Mechanical	OK	Less sensitive area
Vik, Jæren	1	24300	Mechanical	OK	Less sensitive area
Haastein, Stavanger	1	149200	Chemical precipitation	OK	Less sensitive area
Haugesund		20200	Mechanical	OK(?)	Less sensitive area
Odda	2	7000	None	Upgrading	Less sensitive area
Sletten, Bergen	1-2	35700	Mechanical	Monitoring +Evaluation	Less sensitive area

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[1] Highly varying due to industrial effluents

Knappen, Bergen	2-3	43500	Chemical precipitation	Monitoring+ Evaluation	Sensitive area
Holen, Bergen	2	51900	Mechanical	Monitoring +Evaluation	Less sensitive area
Kvernevik, Bergen	2	22100	Mechanical	Monitoring +Evaluation	Less sensitive area
Førde	2	8550	Mechanical	OK(?)	Less sensitive area
Ålesund	2	13000	Chemical precipitation	OK	Less sensitive area
Molde *RA1* *RA2*	2	 6900 11000	 Mechanical Mechanical	 OK(?) “	Less sensitive area
Trondheim: *Ladehammeren* *Høvringen*	 2 2	 41300 93500	 Chemical precipitation Mechanical	 Monitoring +Evaluation “	Less sensitive area
Orkanger	2	7200	No treatment	Upgrading	Less sensitive area
Stjørdal	2	9100	Chemical precipitation	OK(?)	Less sensitive area
Verdal	2-3	8100	Chemical precipitation	OK(?)	Less sensitive area
Steinkjer	2-3	12100	Chemical precipitation	OK(?)	Less sensitive area
Namsos	2	3300	Mechanical	OK(?)	Less sensitive area
Rana	2	13300	Mechanical	OK(?)	Less sensitive area
Bodø	2	37400	Mechanical or none. 12 discharges	Upgrading	Less sensitive area
Narvik	2	4800	Mechanical. 3 discharges	Upgrading	Less sensitive area
Harstad	2	24000	Mechanical or none. 7 discharges	Upgrading	Less sensitive area
Tromsø	2	53000	Mechanical or none. 11 discharges	Upgrading	Less sensitive area
Alta	2	15600	No treatment. 6 discharges	Upgrading	Less sensitive area