The Pollution and Protection of the Inner Oslofjord: Redefining the Goals of Wastewater Treatment Policy in the 20th Century

The main source of pollution in the inner Oslofjord in the 20th century has been municipal sewage discharges from the city of Oslo. At the beginning of the 20th century, pollution was limited to the coastal waters and the harbor area of Oslo, in the vicinity of sewer outlets. High bacteria content caused a health hazard that city authorities attempted to reduce by constructing a sewerage system, including intercepting sewers and wastewater-treatment plants. Due to population growth, the impact area of increasing wastewater loading expanded. The entire inner Oslofjord was found to be affected in the 1930s. Scientific studies linked municipal sewage discharges to an increase in the algal production. In the 1940s, the bottom layers were found to be anoxic. The Oslo sewerage authorities were aware of the fjord's pollution, but regarded organic matter as the major problem and the activated sludge method as the best solution. The role of nutrients was not commonly acknowledged until in the late 1960s. Phosphorus removal was taken into use in the 1970s, and nitrogen removal was introduced in the late 1990s. Removal of nutrients has resulted in the slow recovery of the fjord.

INTRODUCTION

Municipal wastewater discharges and water pollution are interconnected. Ever since the introduction of water pipes and sewers, water pollution began to attract attention in large cities of Western Europe and the USA (1–4). In Oslo, water pollution was discussed as early as at the end of the 19th century (5, 6). The first wastewater-treatment plant was built in Oslo already in 1910. In the following decades, several intercepting sewers and treatment plants were built, but it took until 1983 to connect all the households of Oslo to a wastewater-treatment plant. Why did it take nearly a century to build an effective wastewater-treatment system in Oslo?

Decision-making processes affecting environmental protection involve complicated issues. The aim of this historical presentation is to provide an overview of the discussions behind the development of an effective wastewater-treatment system in Oslo. Technical, scientific, social, and economic aspects play an important role in this process. However, this article focuses on the role of technical and scientific factors. The main questions to be answered are: How experts perceived the water pollution of the inner Oslofjord at various times and which solutions were proposed to solve the changing pollution problems?

An important precondition for solving the problem is common agreement on the nature of the problem and how to solve it. According to constructivist theory, a fact is established as a fact only when all relevant social groups agree that it is a fact. Similarly, a specific technology does not work on its own, but only when all relevant social groups agree that it works. Establishment of a fact as a commonly accepted fact and deciding on a specific technology as a solution to a specific problem can be called a negotiation process. It includes debates, discussions and interpretations presented by various relevant social groups who are trying to convince others which technical alternative is the best one for solving the problem. A specific technology is applied only after its capability has been acknowledged by the relevant groups (7–9).

One way to learn from the past is to follow society in the making (8). The aim of this historical presentation is to clarify the discussions behind the long-term development of Oslo’s wastewater-treatment system, mainly from the point of view of the technicians and scientists involved. The study is based on archival material of Oslo’s municipal decision-making political authorities, scientific reports and articles on wastewater management, and local newspapers. Physically, Oslo does not belong to the catchment area of the Baltic Sea. But in a cultural sense Oslo belongs to the Baltic Rim, and it participates in environmental discussions and cooperation in the Baltic Sea region. Hence, it is relevant to present the environmental history of Oslo in the Baltic context.

Physical Features of the Fjord

The Oslofjord is about 100 km long, stretching from the Skagerrak in the south to the city of Oslo in the north (Fig. 1). The inner Oslofjord is a long, narrow and deep basin (maximum depth 164 m). It is separated from the outer fjord by the Drøbak Sound (depth 27 m), which effectively prevents good water exchange between the inner and outer parts of the fjord. The inner fjord consists of 2 deep basins, the Vestfjord (160 m deep) and the Bunnefjord (160 m deep), and 3 shallower basins, the Lysakerfjord, the harbor area of Oslo, and the Bekkelaget basin. Due to the limited water exchange between the different deep basins,
the Oslofjord is highly vulnerable to nutrient loading: the deeper water layers easily become anoxic.

**Pollution of the Harbor Area**

In 1900, a committee was appointed to consider the introduction of a water closet system and reconstruction of a sewerage system in Oslo (10). The committee engaged A. Holst, who was a professor of medicine at the University of Oslo, to study the effects of discharged municipal wastewater on the seawaters of the harbor area and to evaluate its effects on public health (10). He found that the harbor basin had been heavily polluted by wastewater from the city of Oslo. According to Holst, the self-purification ability of the sea was not able to cope with the pollutants in the wastewater. Organic matter sank to the bottom, and in the anoxic conditions there, poisonous and bad-smelling hydrogen sulfide was produced. This hydrogen sulfide polluted the air and was also believed to cause acute or chronic poisoning. In the harbor area the bacteria content was high, which was a potential hazard to public health (11).

The committee concluded that the city should construct a proper wastewater-removal system (10). In 1910, the first wastewater-treatment plant was completed in Filipstad. Its treatment method was called the Rinsch skive, which consisted of a rotating disc, which mechanically removed sludge, skimmerings and suspended solids from the wastewater (12). In 1911, Oslo’s second treatment plant, the Skarpnsno plant, was taken into operation. It was a fermentation tank designed to break down organic matter (12). In addition, several small mechanical treatment plants were constructed in the following years (Figs 2 and 3).

As the population increased, wastewater discharges increased as well. Thus, small treatment plants were insufficient. In 1920, the city council accepted a plan for a new sewage system. The aim was to treat sewage before discharging it via a single outlet into the fjord. This was regarded as sufficient to solve the harbor area’s pollution problem (13).

International experience and discussions of wastewater-treatment technology were followed in Oslo. In 1925, a delegation travelled to England to study the recently invented activated sludge technique. It was considered to be the best available treatment technique, because it was able to remove 90–95% of the organic matter and 98–99% of the bacteria content, and it produced clear and odorless water. O. Owe, the director of the Oslo Sewerage Authority, claimed in 1926: “One can be quite sure that the inner harbor areas will be purified for all of its pollution if treated in an activated sludge plant” (14). After this trip the Oslo Sewerage Authority applied for funds to refurbish the Skarpnsno plant with activated sludge facilities and to construct a new plant in Festningen (15). Funds for the Skarpnsno activated sludge plant were granted in 1926, but for the Festningen plant not until in the beginning of the 1930s.

The Oslo chief technical officer, H. Samuelsen, opposed the new technology as an unproven alternative. According to him it would be better to continue to discharge untreated wastewater into the fjord to determine if it caused any drawbacks (15). The Festningen mechanical plant was taken into operation in 1933 to treat the wastewater from 170,000 people (16). The removal of suspended solids was expected to solve the pollution problem caused by putrifying sludge. O. Owe also stated that the self-purifying capacity of the fjord made it unnecessary to apply activated sludge treatment on a large scale (17).

**Pollution of the Inner Oslofjord**

The pollution of the fjord was broadly discussed by professionals and by the public in the 1920s and 1930s. On warm summer days tens of thousands of people went by boat or bus to various locations on the fjord in order to enjoy outdoor activities (6). Swimming competitions in the harbor area were popular and attracted thousands of spectators. However, due to water pollution the Board of Health had to move the locations of these competitions, and several public bathing places were closed down (18, 19).

In 1932, Afien-posten, the leading Oslo newspaper, stated that “the sea water was worse than ever before”, and accused the Oslo Sewerage Authority of irresponsibly discharging untreated wastewater into the fjord. The Authority, in turn, blamed the municipal political authorities for not having allocated the necessary funds for reconstructing the sewerage system (20).

The newspaper repeatedly called attention to the greenish-grey color of the water, which made it look dirty and smelly and the shores muddy and sticky. The sludge from the treatment plants was dumped in the vicinity of the harbor, between the Langøyene Islands, and it was proposed to be the main cause (21). Owe, the director of Oslo Sewerage Authority, agreed that the color was caused by increased algal production, but argued that this was a result of hydrographical conditions, i.e. the algal masses were entering from the outer fjord into the inner fjord. He did not believe that the municipal wastewater discharges were the cause of the problem (17). This explanation was supported by a chemist who claimed that warm summers provided optimal conditions for algal growth (22).

Alerted by the pollution of the fjord, marine scientists of the University of Oslo carried out a study on the impacts of sewage discharges on the marine life. The increased phytoplankton production in the surface waters in the summertime was assumed to have been caused by increased wastewater loadings. Professor T. Braarud, from the Institute of Marine Science, concluded...
in 1945 that there was a positive connection between wastewater, its phosphorus content, and increased phytoplankton production (23).

Braarud stated that organic and inorganic matter and nutrients had a positive impact on the fjord, increasing plankton production that would provide more food for marine fauna, which, in turn, could be exploited by the people living around the fjord. Nevertheless, he pointed out that it was necessary to establish a scientific basis for improving the state of the inner Oslofjord (24). According to Braarud, an evaluation of the impacts of pollution on the marine life should be made from an economic point of view; however, sanitary, hygienic, and aesthetic requirements were to be taken into consideration. He emphasized that the different aspects and uses of the fjord might conflict with each other.

The Oslo Sewerage Authority saw the pollution problems from a different angle than did the marine scientists. The engineers had also recognized the problem of oxygen depletion, but they attributed this to the discharge of organic matter. The sewerage plan of 1938 claimed that undissolved and dissolved organic matter was the main source of pollutants in the Oslofjord water. The oxygen level was not high enough in the harbor for the decomposition of organic loads, which sank to the bottom and developed into a putrifying sludge (25). It was estimated that 95% of the organic matter could be removed in an activated sludge plant. The largest treatment plant in Festningen was refurbished in 1944 with a sedimentation process, not with activated sludge facilities, with the result that only 20% of the organic load was removed (26). The self-purifying capacity of the fjord was regarded to be capable of coping with the wastewater discharges, thus a large proportion of wastewater was treated either inefficiently or discharged untreated directly into the fjord.

Debating Wastewater Impacts

In 1946–1950, E. Føy and F. Beyer of the Institute of Marine Science studied the impacts of municipal wastewater discharges on the biological system of the fjord. The average oxygen content in the deeper layers was found to have diminished. In the deep Bunnefjord, below 70 m to a depth of 150 m, oxygen was depleted, and as a consequence the bottom of the fjord was biologically dead (27).

At a meeting organized by a local engineers’ organization in 1954, Professor Braarud gave a lecture about the pollution situation as the marine scientists now perceived it. He emphasized that the state of the fjord and its marine life had reached a stage that had to be taken into serious consideration in the future planning of wastewater treatment. It should be known what to treat, why, and how. Which factors in the wastewater increased the production of plankton, organic matter, nitrogen or phosphorus pollutants? Marine scientists at the University of Oslo argued that nutrients increased algal production. While refurbishing the sewerage system, the possible impacts of nutrients should be taken into consideration (28). Braarud also called for municipal cooperation in the fjord area: even if municipalities were divided by boundaries, pollution was not.

A debate followed his lecture and it was agreed that a broad investigation was needed to solve the pollution problems. In addition, generally accepted guidelines and principles for developing the sewerage system were needed. The chief technical officer commented that solving the pollution problems was one of the most urgent tasks and that construction of wastewater-treatment plants should be given high priority (28). However, the policy of the Oslo Sewerage Authority remained controversial.

At that time, very little information was available on methods of removing nutrients. In the 1940s, promising experiments on nutrient removal had been carried out in the United States, but these results were not convincing. In Norway, E. Føy had developed his own electrolytic method to remove nutrients, organic matter, sludge and bacteria. In principle, it was a complete treatment method with no need for biological pre-treatment (29).

The municipal politicians of Oslo had to decide whether to apply activated sludge treatment or Føy’s electrolytic treatment. The Oslo Sewerage Authority had financed early laboratory experiments of electrolytic treatment, but it was also planning a large activated sludge plant at Bekkelaget to serve the eastern areas of Oslo. S. Bechholm, the director of the Oslo Sewage Authority, questioned the role of nutrients in pollution and proposed to construct an activated sludge plant, which was an acknowledged treatment method (30). Nevertheless, the city council decided to construct both plants (31, 32). The Bekkelaget activated sludge plant was taken into operation in 1963, treating the wastewater produced by 150 000 thousand people, and removing 60% of the organic matter. Nevertheless, it took several years before the plant began to operate properly. The electrolytic treatment pilot plant was in operation only from 1958 to 1963.

INTRODUCTION OF NUTRIENT REMOVAL:
A NEW ERA

In 1960, the municipality of Oslo decided to launch an extensive research program to clarify the impacts of wastewater discharges on the inner Oslofjord and to find technical solutions for the pollution problem. The study was carried out by the Norwegian Institute of Water Research (NIVA) in 1962–1965 and its costs were shared by 10 municipalities surrounding the inner Oslofjord. The aim was to study how physical, biological and chemical processes and wastewater discharges interacted in the fjord (33). It was found that the limited water exchange between the inner and the outer fjord exacerbated the pollution. Wastewater discharges fertilized the fjord, and plankton production in the upper water layer, consequently, resulted in oxygen depletion in the bottom layers. As a result, no animal life was found in some parts of the fjord (33).

In 1970, NIVA presented principles for improving wastewater-treatment (34) (Fig. 4). Organic matter in wastewater was no
longer regarded as a major problem. As phosphorus was regarded to be essential for algal growth, wastewater treatment to improve the state of the inner fjord was to be based on the removal of phosphorus. The treatment technology was now available. The inner fjord was a suitable recipient for wastewater, but the treated wastewater was to be discharged into the middle layer of water column where it was expected to cause less harm. The municipalities were advised to make a common plan for wastewater management (34).

Meanwhile, the Oslo Sewerage Authority continued to work on its own wastewater-treatment plan. The wastewater from Oslo’s western districts was discharged untreated into the fjord. A new activated sludge plant in Lysaker was planned to solve this problem (35). The Oslo Sewerage Authority was convinced that removal of organic matter was a priority, but it was also necessary to monitor the recipient to control the impact of wastewater discharges (36). However, in 1970 the Oslo Sewerage Authority also accepted the proposal made by NIVA for the future planning of the sewerage system (37).

In 1975, the municipalities of Asker, Bærum, and Oslo started to plan a new central wastewater-treatment plant which was to be a combination of mechanical, biological and chemical processes (38). In 1976, an intermunicipal company, VEAS, was established to plan, build and run the plant. The costs of biological treatment were, however, regarded to be too high in relation to the treatment efficiency, and biological treatment was omitted (39). The VEAS plant was taken into operation in 1983. It treated sewage mechanically and chemically, and then discharged it into the deeper layers of the Vestfjord. At this time all municipal wastewater was finally being treated.

**NITROGEN REMOVAL: A MATTER OF CONSEQUENCES**

The VEAS plant improved the state of the surface water gradually, and this was good news from a recreational point of view. However, the oxygen deficiency in the deeper water layers remained a critical problem. In 1990, the bottom of the Bunnefjord was still dead below a depth of 70 m. Some parts of the Vestfjord also suffered from oxygen deficiency. A number of investigations carried out by NIVA concluded that biological treatment as a supplement to mechanical and chemical treatment would improve the condition of the deeper water layers. It was also pointed out that the starting point in future planning should be the determination of what kind of natural conditions were desired in the fjord. The different user interests should be considered and a cost-benefit analysis made (40). This was the same suggestion that Braarud had made 40 years ago.

When Norway signed the North Sea Declaration in 1987, the government was obliged to reduce Norway’s nitrogen discharges into the North Sea by 50%. To fulfil this obligation the national political authorities instructed the municipality of Oslo to reduce its nitrogen loading by 70%. This demand caused a new debate. Both marine scientists and politicians of the city of Oslo questioned whether nitrogen loading from the inner Oslofjord was having any effect on the North Sea at all. The municipal politicians questioned why Oslo should have to remove 70% when only 50% was demanded (41, 42). NIVA estimated that nitrogen’s role in limiting algal production was minor in the inner Oslofjord compared to that of phosphorus. In the open sea, the situation was the opposite (43). J. Gray, a professor in marine biology at the University of Oslo, criticized the demands to reduce nitrogen discharges of municipal wastewater into the North Sea. According to Gray only a fraction of the pollution stemmed from this source (42). Nevertheless, in 1996 nitrogen removal was introduced in the VEAS treatment plant. In addition, it was decided to construct a new Bekkelaget plant to meet the nitrogen removal requirement of 70% (45) (Fig. 5).

The state of the inner Oslo fjord has improved since the 1980s due to diminished plankton production after the introduction of phosphorus removal. The state of the bottom layers continues to be poor. In the Bunnefjord, the bottom layer was still dead up to 70 m (46). The impact of nitrogen removal will be seen in years to come.

**CONCLUSIONS**

The process of building an effective wastewater-treatment system in Oslo did not bring linear improvement. The goals of wastewater-treatment were repeatedly challenged by new problems and methods that demanded re-evaluation of existing concepts. This rethinking was formulated in debates over wastewater impacts and attempts to improve wastewater-treatment technology. The most important new goals set in the 20th century have involved the transition from removal of organic matter to removal of nutrients.

In the beginning of the 20th century the pollution problem in Oslo was found to be limited to the harbor area and the coastal waters. Public health was the main concern, as high bacteria levels and hydrogen sulfide caused a health hazard. An attempt was made to solve this pollution problem by treating wastewater mechanically and discharging wastewater via a single outlet into the fjord. As organic matter had come to be regarded as the most significant problematic substance in the wastewater, removal of organic matter became the main goal of wastewater treatment after 1910.

In the 1920s and the 1930s, the entire open fjord was found to be affected by municipal wastewater loading. The water stank, had a greenish color and an expanding algal population. A con...
connection between wastewater and increased algal production was recognized by marine scientists in the 1930s. However, at that time, the scientists were not sure if the nutrients had a positive or negative impact on the fjord. In the late 1940s and in the mid-1950s, the impacts of nutrients on aquatic ecosystems were better understood. Meanwhile, the pollution continued with the result that the deep areas of the fjord became anoxic. Consequently, introduction of nutrient removal was demanded by natural scientists.

During this time the engineers believed that organic matter was the problematic substance in the wastewater. It took 20 years before nutrient removal was recognized in the 1970s as the main objective of wastewater-treatment by the engineers at the Oslo Sewerage Authority. Why did the Oslo Sewerage Authority stick to their original position for such a long time?

The most obvious explanation for this seems to be that the Oslo Sewerage Authority operated in a European wastewater-engineering context, which regarded organic matter as the main pollution source. Different techniques had been developed to remove organic matter, but the development of nutrient removal started much later. Due to this engineering tradition, Oslo applied treatment methods that had been developed for different circumstances than those of the Oslofjord. The marine scientists had to convince the Oslo Sewerage Authority that the inner Oslofjord’s pollution problems differed from those of a river. Besides they had to convince the Authority that the solution had to be based on nutrient removal and not solely on removal of organic matter.

Therefore, the changes in the goals for wastewater treatment can be interpreted as results of negotiated changes. In this process of negotiation, the main goal has been to discuss and decide the nature of the pollution problems and the nature of technical solutions. This process has been extremely complex and time consuming. The combined complexities of the nature of the pollution problems, of the solutions and of the negotiations needed to reach agreements in the technological and scientific community were a crucial cause of the delay in building an effective wastewater-treatment system. It seems fair to state that throughout the 20th century the goals of wastewater treatment were re-defined several times.

References and Notes


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