

Modernizing sewers and wastewater systems with new technologies

After continuous problems and challenges with dead fish and oxygen depletion in the waters, Denmark initiated an action plan for Danish waters to reduce pollution in the late 1980s.

The action plan puts focus on stricter criteria for wastewater treatment plants. Over the years, the plan has been revised three times to ensure continuity in the work. As a result, Danish waters are significantly cleaner today.

Since 1987 the pollution caused by wastewater has been reduced by 80 - 90 % - depending on the type of pollutant. Upgrading the wastewater treatment system with a number of new and innovative Danish technologies is one of the main contributions to this success. However, education of staff, improved legislation and good cooperation between several stakeholders played an important role as well.

Background: the challenge in 1987

In 1987 the Danish government decided that future discharges from wastewater treatment plants had to live up to strict criteria for the main pollutants; organic matter, nitrogen, and phosphorus. The decision was a result of severe oxygen depletion in Danish coastal waters causing fish and lobster mortality. The aim was to reduce the overall discharge of nutrients significantly. The ambitious criteria set in the first Action Plan were effluent concentrations from wastewater treatment plants of 8 mg nitrogen and 1.5 mg phosphorus per liter, and these were to be met before 1993. Denmark was the first European country to implement strict nutrient regulation. This Danish regulation was the basis for the EU Urban Waste Water Directive from 1991.

At this point, Denmark had a rather well-developed wastewater management system. A significant amount of wastewater was treated mechanically and biologically, reducing the concentration of organic material and particles. The wastewater management system with sewers, stormwater tanks, treatment plants and outfalls was more comprehensive and



advanced compared to most countries in the world. During the preceding 20 years, wastewater treatment had been concentrated at municipality-owned treatment plants, handling wastewater from households and from small industries. Bigger industries had their own wastewater treatment plants. Financing wastewater treatment was based on fees from users, without public subsidies. The fee for households was based on wastewater volume and the fee for industries was based on a mix of volume and pollution load.

The large investment in wastewater infrastructure in the 1970s and 1980s could easily be utilized for future development.

The Danish development

The Danish concept for improving the quality of receiving waters was implemented in three steps. The first step was to reduce nutrient discharges from bigger cities, the second step was handling stormwater discharges and the third step was improved wastewater management in rural areas. The environmental effects of each step have been followed closely by an intensive monitoring program that quantified the effects and also pointed out which additional measures were needed.

For planning purposes, the Danish Hydraulic Institute (DHI) developed software for urban run-off simulations with conceptual as well as detailed hydraulic models, while the sewerage network owners mapped the layout and the loading of the sewerage system.

Step 1: reduction of nutrient discharges from treatment plants

In 1988 Danish companies developed advanced biological treatment technologies for removal of nitrogen and phosphorus. The Biotenitro process and the Biotenipho process were developed and patented by Danish companies. Parallel to the technological development, a theoretical description of the biological process was modeled by researchers at the Technical University of Denmark (DTU). The technologies and theoretical developments were world leaders at that time and still form the international platform for biological wastewater treatment processes and modeling. The result was that this technology was exported worldwide. The technology could be used to upgrade existing treatment plants without major loss of existing investments.

In the period from 1995, with demands for further quality improvements in the effluent from these processes, they were developed and combined with advanced control strategies. Today these technologies are still market leaders.

Table 1. The percentage of wastewater in Denmark subject to advanced treatment

1987	1993	2005	2006
0.5%	54%	89.9%	91.2%

Step 2: reduction of discharges from rain and stormwater

Until 1950 Danish sewerage was based on sewer systems handling both wastewater and stormwater – combined sewer systems. Since then new sewerage has separated wastewater



from stormwater, with the wastewater being transported to a central treatment plant and the stormwater being discharged to the nearest surface water – separated sewer systems.



However, since the sewers in central parts of all cities were constructed before 1950 and treatment plants are typically situated at the endpoint of these sewers, heavy rainfall still led to discharges of a mixture of untreated sewage and polluted stormwater. Despite having implemented advanced treatment at treatment plants, discharges during wet weather still accounted for a substantial amount of the overall discharge of nutrients.



This discharge of stormwater affects the receiving water quality. Consequently, initiatives over the past 20 years have aimed at reducing discharges of untreated sewage from combined sewer system overflows.

The solution to reduce stormwater discharges from combined sewer systems has been to build storage tanks and big storage sewers, which in combination with advanced control of the sewer system has allowed a much more stormwater to pass through a wastewater treatment plant before discharge.

Discharge of wastewater from combined sewers has been regulated by the municipalities through a maximum permitted number of discharges per year or a maximum volume per year. Even with the substantial investments over the years, stormwater discharges still account for a significant amount of the overall wastewater-related discharges, as can be seen in the table below.

Table 2. Importance of stormwater discharges relative to the overall discharges from treatment plants in 2006

	Million m ³	t COD	t N	t P
Separated discharges	23%	34%	9%	20%
Combined discharges	5%	21%	10%	24%

Less stormwater discharge from combined sewers has resulted in improved quality of receiving waters in cities and near industries. Bathing-water quality has been significantly improved so that bathing is possible in and near many cities. In sensitive areas, the reduction of microorganisms in the discharge through UV-radiation and fine screening has had a further positive impact. Overall, this has resulted in improved welfare for citizens and made areas more attractive for tourists.

Improved treatment technologies have also been implemented in connection with industrial discharges. The combined effect of treatment at industrial and municipal treatment plants and wet weather discharges has resulted in a reduction of more than 80 percent for both nitrogen and phosphorous.



Step 3: reduction of wastewater discharges from households outside sewer areas

Discharges of wastewater from households outside sewer areas have been reduced since the turn of the century by two measures. One is local biological mini-treatment plants, often for single houses, and the other is collection of wastewater and transport to centralized treatment plants. There are about 100,000 households outside sewer areas where better treatment has to be implemented.

Several types of small-scale mini-treatment plants have been developed that are certified to fulfil the highest EU standards for cleaning sewage.

Exporting Danish technology

There have been significant exports of Danish wastewater technology despite the lack of a large domestic market for suppliers and consultants. Grundfos is a world-leading producer of pumps for water and wastewater and Danfoss leads the world in industrial automation. Together with these companies, a number of other Danish companies have developed significant exports of about 1 billion euros each year. There are around 100 Danish companies exporting wastewater technology, including companies such as COWI, Ramboll, Grontmij, Carl Bro, Krüger and DHI Water, Environment and Health.

Legislation, education and cost-effectiveness helped develop long lasting solutions

Developing the proper technologies is not sufficient to ensure that they are implemented. One of the driving forces behind the innovation of new treatment technology was an ambitious Water Act passed by the Danish Parliament in 1974. This helped focus on environmental issues and therefore the technologies had already been developed when the first Action Plan for the Aquatic Environment was adopted by the Danish Parliament in 1987. The Action Plan was followed up by second and third Action Plans as more knowledge became available and measurements showed that the actions stipulated in the first Action Plan were not sufficient to reach the goals. All three Action Plans have been formulated in a non-exclusive way, meaning that they have suggested treatment processes rather than demanded a given treatment technology.

All investments in sewage collection and treatment are financed by the consumers connected to the collection system. The activities needed to ensure proper performance of the system are carried out by the municipal authorities, but the costs of all these activities are registered on separate accounts. The municipal authorities stipulate the expected performance of the system in quantifiable terms in a legal document that is adopted after a public hearing. In this way, all investments are transparent and can be understood by consumers.

A significant program to upgrade the qualifications of sewage-system personnel has been implemented. Plant managers have to pass an exam organized by the government, while employees have upgraded their competences through continued education for all types of work. Staff with academic backgrounds have been employed at bigger treatment plants in order to optimize processes and operation.



During the first stages of implementation of the Action Plans, focus was to get the treatment plants to fulfill the treatment requirements for which they were designed. Further research and development soon led to optimization of the operation of the treatment plants which meant that treatment could be reduced or standards could be raised. It became obvious that the general requirements for treatment should be increased. The problem was that for some plants further treatment would imply disproportionate increases in costs because the plants could not be optimized further, whereas further treatment at other plants could easily be achieved. The solution was to implement an economic incentive, i.e. a tax on discharges of nutrients. In this way, all plants had an incentive to minimize pollution further, but without disproportionate investment at locations that had fulfilled the criteria stipulated only a few years earlier.

Success: clear definition of roles

One of the reasons for the successful implementation of the Action Plans for the Aquatic Environment was a clear and unambiguous definition of roles and responsibilities of the many stakeholders needed to implement the Plans. The Danish setup, already defined in the 1970s, was ahead of its time. The setup in the national legislation consists of four corner stones:

- **National legislation** stipulates the national environmental objectives and general targets to be met based on scientific assessments of needs for reductions and how each sector can contribute to achieving the required reduction. The national legislation states general recommendations for allowable concentrations of organic matter and nutrients in discharges from treatment plants.
- **Regional water boards** measure the physical, biological and chemical status of each surface-water area in the region and assess whether the general recommendations are sufficient to meet the objectives within a reasonable time. If not, the regional water board will suggest specific actions by treatment plants or other stakeholders in order to ensure that the objectives are met. Point discharges of pollutants must be approved by the regional water boards.
- **Research institutions** are asked for recommendations regarding the feasibility of the stipulated targets and whether technical means to meet the targets are available.
- **Suppliers, constructors and consultants** are kept up-to-date because only the targets are defined, not the means. This means that there is constant pressure for innovation in order to meet targets in a more cost-effective manner, reducing the overall need for resources.

During the past 20 years, all large Danish treatment plants have been renovated and upgraded. The number of plants has been reduced by more than 50 percent in order to meet the goals; and further reductions are under way. Small and inefficient treatment plants have been closed down and treatment has been centralized.

During this period, industries have reduced their discharges significantly, driven by user payment for wastewater volumes and amounts of pollutants.



Twenty years of improvement

During the past 20 years, the management of wastewater in general has been improved, so in total the load of organic material to receiving waters has been reduced by almost 90 percent - from 95,000 to 13,000 tonnes BOD per year.

In the period 1989 to 2006 the nitrogen load to receiving waters from wastewater and stormwater has been reduced from 27,000 to 7,000 tonnes per year. Similarly, the phosphorus load has been reduced from 6,500 to 0.9 tonnes per year.

The improved treatment of wastewater has resulted in a significant improvement in bathing-water quality along the Danish coast. Nearly all beaches in Denmark have good bathing-water quality.

Climate change and privatization remain challenges

The most important challenge for urban drainage systems is mitigation of and adaptation to anticipated anthropogenic climate change. Systems to handle urban drainage consume large amounts of electricity. Even though most of the sewage is transported by means of gravitation, numerous pumping stations are necessary - both in the sewerage network and at the treatment plants. Sewage treatment itself also consumes a lot of electricity. Studies show that treatment as an end-of-pipe solution is better than omitting treatment because the CO₂ used to produce electricity for treatment is more than compensated for by the greenhouse gasses that the treatment prevents (e.g. methane). The use of sludge to produce electricity by means of biogas production further reduces the production of greenhouse gasses. Nevertheless, optimization of energy consumption in the sector will be a key issue, and actions such as the EU Eco-Management and Audit Scheme (EMAS) must be expected to be implemented in the future as a structured approach to reduce energy consumption.

Adaptation to anticipated climate change will also greatly affect urban drainage structures. The key issues for the sector in Denmark are expected to arise from increased extreme precipitation. This means, that if adaption measures are not implemented, hydraulic performance of the sewer system in cities will deteriorate significantly, treatment efficiency of the treatment plants will be jeopardized because of large hydraulic overloads, and the environmental state of surface waters will also deteriorate because of more leaching of nutrients from land-based sources. Furthermore, the installations needed to treat sewage are often situated in low-lying areas, which make them vulnerable to flooding caused by flash floods as well and storm surges. The pollution caused by flooding of a treatment plant is equivalent to huge discharges, both immediately because of a point discharge and due to less efficient treatment while the biological material in the plant is regenerated.

Another key challenge for the Danish water sector is the planned privatization of the urban drainage sector in Denmark. The privatization differs a little from other types of privatization of utilities which occur quite frequently in EU countries. However, as stated previously, the sector has been able to align well with the socio-economic optima for society as a whole and has also made investments according to recommendations for the public sector as a



whole. Privatization will mean that regulation must be more detailed in order to ensure that the private utility companies make investments and fulfill the stipulated environmental goals in alignment with the political targets for the sector. However, privatization also implies positive effects, one of which is larger units with a more professional staff.

Privatization of water utilities is expected to lead to more focus on economic optimization. This means that there is a need for a more structured approach in setting a price for having a clean environment.

Solutions for the future

The implementation of technologies developed over the past decades has finished in Denmark. However, new technologies show large potential. The leap in technological development within informatics and communications is starting to turn into usable new solutions for the water sector. Present state-of-the-art technology primarily involves online optimization of the activated sludge part of the treatment plant, but often neglects the other parts of the treatment plant and information generated outside the premises. Generation of reliable forecasts and control options on a global scale enables us to include flexible responses to diurnal and extreme fluctuations.

In the future, it may be possible to replace biological treatment with physical barriers, i.e. development of ultrafine membranes that remove solids and perhaps even nutrients. Research indicates that this may well be an optimum solution both in terms of energy consumption and space requirements.

However, technology on its own cannot efficiently solve the anticipated problems the water sector is facing. There is a recognized need for even better collaboration across the different administrative borders in order to ensure that environmental improvements are achieved in a cost-effective manner allowing optimum socio-economic solutions to be implemented. Furthermore, new concepts are needed for managing water in cities that will reduce the overall consumption of resources and at the same time make cities more robust to anticipated climate change. The current state of these technologies allows management of stormwater at a local scale, but solutions at larger scales are currently being studied. Danish research institutions as well as a number of municipalities and suppliers are involved in identifying such solutions.

Danish lessons learned

- The use of standard general recommendations for treatment in combination with the possibility to set stricter treatment requirements if the environment so requires has proved to be an efficient way of obtaining a high and yet cost-effective standard of sewage treatment.
- The Danish tradition has been to stipulate the objectives for the environment and on that basis set operational target values for discharges and suggest means to obtain the target values. This has proven to be an effective way of obtaining cost-effective solutions. Other countries have made legislation based on the means rather than the objectives. These countries often fail to be the first to implement new methods, because there is no incentive to be innovative.



- In some cases there can be an economic benefit when implementing stricter treatment than necessary to achieve the short-term environmental targets. The Danish capital, Copenhagen, systematically invested in more advanced treatment and more storage and treatment of stormwater than was necessary according to the environmental targets for the marine environment surrounding Copenhagen. This has enabled the installation of bathing areas with all amenities in the immediate vicinity of the former industrial harbor, and this has been turned into a highly fashionable and modern city area. This has proven to be a very profitable investment with high return rates for the municipality.
- An efficient cost-recovery system, building on direct payment by the consumers, has enabled a rapid investment rate in enhancing treatment.
- Close collaboration between consultants, suppliers and universities in Denmark on identifying the possibilities for removal of phosphorous and nitrogen opened a large world-wide market. This collaboration is an excellent example of how theoretical knowledge and research can be combined with practical observations in order to meet a demand. Part of the reason may be the Danish tradition of travelling and doing business and interacting closely with many partners worldwide.
- Extensive use of in-service training of personnel as well as the introduction of graduate engineers at treatment plants has greatly improved overall treatment efficiencies. The higher education level has also enabled more rapid introduction of new technology at the facilities. This has enabled more robust treatment adapted to local conditions.
- Part of the successful implementation of more advanced treatment was due to the fact that the level of knowledge about the sewer system was already available. Thus a better design was possible, based on local conditions rather than rules of thumb.

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For more information on the Danish action plan for promotion of eco-efficient technology:
www.ecoinnovation.dk/english