CITY OF COPENHAGEN

DANISH MINISTRY OF THE ENVIRONMENT

The Port of Copenhagen – from a heavily polluted industrial port to a clean and thriving aquatic environment

Today the water in the Port of Copenhagen is just as clean as the water in the Sound, outside the port. Fish, web-footed birds and benthic vegetation have returned, and the people of Copenhagen have taken over the port for bathing, yachting, limited sports fishing, cafés and parks. Just ten years ago the water was unsuitable for bathing and there were only few animals because of the heavy pollution.

Improvement of the aquatic environment is primarily due to investment of almost DKK 1bn (EUR 135 mill.) in the modernisation of the sewerage system. New sewers and wastewater tanks have been established. Modern electronics and advanced computer systems are being used to control wastewater management and to control and forecast developments in the water quality.

The many years of pollution have left large amounts of environmental toxins in the sludge on the seabed in the port. Here lies the next great challenge for the City of Copenhagen's efforts to improve the aquatic environment in the Port of Copenhagen.

Industry is disappearing, but not the pollution

In the 1980s, the southern part of the Port of Copenhagen known as Sydhavnen saw the end of its heyday as an industrial port and was heading towards the end of an era. Cargo ships were moved to a new and modern container port in the northern part of the outer harbour, the navy and the navy dockyard were moved from Copenhagen to a number of other ports in the provinces, and the Port's factories and shipyards disappeared one by one.

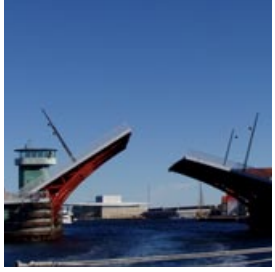
This created new opportunities for making an attractive urban environment in Sydhavnen, and in 1989 the City of Copenhagen decided to change the status of Sydhavnen from an industrial area to a combination of office buildings and residential buildings. Because residential buildings were included in the new plan for the area, open spaces were laid out for recreational purposes. From the beginning, a political objective was that this change should include re-establishment of the aquatic environment in the Port, and in 1992 the City of Copenhagen changed its objectives for the aquatic areas in Sydhavnen. The goal was to make it possible to bathe and fish in Sydhavnen and to vary animal and plant life as much as possible in a culturally created port.

Pools and beaches in Copenhagen harbour and sea

Newly planned pools in Copenhagen harbor and sea

Pools and beaches

In 1990 the environment in the Port was heavily affected by pollution with various types of harmful micro-organisms, large amounts of organic material as well as various types of toxic and persistent chemicals. The visibility in the water was very bad; there was no benthic vegetation in large parts of the Port, while the sludge on the seabed was polluted with mercury and tributyltin (TBT). The entire Port was permanently closed for bathing.



Protected by the islands

The history of the Port of Copenhagen goes back to the establishment of the city in the late 1100s. The city was located on the eastern coast of Zealand, well protected by the narrow strait between Zealand and the island Amager. In the 1600s the city spread to Amager and today the strait between Zealand and Amager is completely surrounded by the city, with the port stretching 10 km between Zealand and Amager and 7 km along the Sound.

Today the port is seven to ten metres deep in the main channel, whereas the water depth is two-three metres in the canals, which were constructed in the 1600s after the Dutch model.

In order for the City of Copenhagen to realise its ambitious goals for the aquatic environment in the Port, they had to make sure that the sewage and rainwater discharge from the city's paved areas was significantly reduced.

When the wastewater discharged had been dealt with, the plan was to work on improving the quality of the sediment at the Port.

Stop pollution

In 1990 the principal cause for the continued pollution of the Port of Copenhagen was that the sewerage system overflowed when it was raining. Therefore, the City of Copenhagen began to modernise and renovate the sewerage system at the Port in 1992. The number of overflow sites in the Port was reduced. At the same time the City of Copenhagen built a number of wastewater tanks where rain and sewage are retained when it rains so much that the treatment plants cannot cope with the amount of sewage and rainwater being led to the treatment plants.

Copenhagen's sewerage

Expansion of the sewerage system in Copenhagen started accelerating in earnest in the 1850s. Hygiene in the city needed improvement. The sewers led the untreated sewage directly into the Port up to 1900. After this the sewerage system was redirected so the sewage was led into the Sound - 700 m from the coast. At the same time the City of Copenhagen began to treat the sewage before it was led into the sea, and since then the plants for sewage treatment have regularly been extended and centralised. In 1980 Denmark's largest sewage treatment plant "Lynetten" was inaugurated. This sewage treatment plant and Denmark's third largest treatment plant "Damhusåen" are responsible for treating most sewage in the Copenhagen area.

From the beginning, the sewerage system of Copenhagen was designed to drain off both sewage and rainwater. When heavy rain and thaw expose the sewerage system to peak loads there is a risk of overflow. From the beginning the sewers were therefore constructed with overflow structures to prevent overflow sewage from flowing into highways and byways. In 1990, 95 overflow structures led the diluted sewage directly into the Port of Copenhagen.

Wastewater is "stored" in the overflow tanks when there is a risk that sewers and treatment plants could be overloaded as a consequence of heavy rain or thaw. When there is capacity to treat the wastewater again, it is released from the overflow tanks. The overflow tanks are

controlled by a modern IT system linked to a central IT system monitoring and controlling the entire wastewater system in Copenhagen.

The City of Copenhagen has invested approximately EUR 55 mill. in modernisation of the Port's sewerage system. Most of the costs are linked to improving the water quality at the Port. At the same time the City of Copenhagen has invested EUR 30 mill. in modernisation of the sewerage system, which is necessary to reduce pollution of the local aquatic environment outside the port. Further investments are planned for Copenhagen's sewerage system of almost EUR 40 mill.

New urban area with a separate rainwater system

At the same time as the change of the Port's status as an industrial port, the new urban development "Ørestaden" was built. Ørestaden borders directly on the Port. Here the sewerage system is constructed so the rainwater from the paved areas runs in an independent system, without connection to the system that has to handle the actual sewage. The rainwater collected from the paved areas is reused in the recreational areas in Ørestaden. Treatment is necessary as analyses have documented that rainwater drained off streets and other paved areas is not clean enough to be reused or directed into the aquatic environment.

A new warning system safeguards bathers

Today Copenhageners can swim in two different harbour swimming basins and more are planned. This only succeeded because an efficient and detailed warning system was established. It is true that the quality of bathing water is good during most of the bathing season, but without total redirection of the existing sewerage system it is inevitable that the sewerage system will overflow during heavy rainfall. Overflows happen now and again near most urban areas in both Denmark and the rest of the world. The City of Copenhagen would not allow bathing in the Port without knowing the bathing water quality at all times. As the warning system can warn bathers immediately against bad bathing water quality, the door was now open for health authorities and politicians to allow bathing in the Port.

The system works by sensors and water-level gauges in the overflows registering the overflows, and the calculating sewage amounts discharged. As soon as an overflow is registered, a text-message is sent to a bathing water official. The movements of the current in the Port are calculated by a bathing water model on the basis of the current water levels and meteorological conditions. Because the bathing water model automatically records the amounts of sewage discharged, the current actual concentration of bacteria is calculated throughout the Port. With this "water forecast", the bathing water official can quickly get an overview of where in the Port the bathing water quality is unacceptable, and warn the bathing site where the quality of bathing water is threatened. Via the water forecast it is therefore also possible to see when the quality of bathing water is acceptable again and bathing can be resumed. When bathing can be resumed, the system informs the harbour swimming basins. The public can follow the quality of bathing water in the harbour swimming basins and at the beach at Amager Strandpark at the website http://www.miljoe.kk.dk/vandmiljoe/badevandsudsigt.

It cost approximately EUR 86,000 to establish the warning system. Operation costs EUR 16,000 annually, including minor changes in the set-up of the model. Operation covers

the entire year and also covers Kalveboderne and the near-shore part of the Sound from Kastrup to Hellerup beach.

The result: improved hygiene, health and environment

The City of Copenhagen and not least the water have benefited from the efforts.

Less pollution

The City of Copenhagen's modernisation of the sewerage system has reduced discharges of diluted sewage into the Port from 1.6 mill. m3 in 1996 to 350,000 m3 in 2007. The amount of material in suspension annually discharged into the Port has been reduced from 161 tonnes to 35 tonnes, and the oxygen consumption of the material discharged has decreased from 280 tonnes oxygen to 61 tonnes oxygen. Similarly, pollution with heavy metals has fallen from 450 kg to 100 kg (Table 1).

Table 1: Discharged amounts of materials into the Port of Copenhagen via overflow.

Year	1995	2004	2007
Sewage m^3/year	1,600,000	700,000	350,000
Kg per year			
Material in suspension	161,600	70,700	35,350
Bio chemical oxygen consumption, BI5	59,200	25,900	12,950
Chemical oxygen demand COD (Cr)	280,000	122,500	61,250
Total nitrogen	11,760	5,145	2,573
Total phosphorus	3,104	1,358	679
Heavy metals, kg per year			
Arsenic (As)	3.520	1.540	0.770
Lead (Pb)	48.000	21.000	10.500
Cadmium (Cd)	0.336	0.147	0.074
Chromium (Cr)	6.560	2.870	1.435
Copper (Cu)	67.200	29.400	14.700
Mercury (Hg)	0.208	0.091	0.046
Nickel (Ni)	6.080	2.660	1.330
Zinc (Zn)	336.000	147.000	73.500
Sum of heavy metals	467.904	204.708	102.354

Improved hygiene

Reduction in the sewage amount discharged has contributed to a significantly improved quality of the bathing water. Therefore, good quality of bathing water has been achieved in the northern part of Sydhavnen. The warning system ensures that the public is warned in the few cases where the water is polluted with overflow water. Because the Port of Copenhagen is covered by a modern warning system, it is safer to bathe in the Port of Copenhagen than in bathing areas with fewer overflows, but without similar warning systems.

More recreational activities

The harbour swimming basins are a good example of how a sports facility becomes very popular and significant when the activities are carried out with fun, joy and pleasure. Apart from giving Copenhagen an oasis for recreation, the facility has derivative effects for public health. Through fun and pleasure, inactive citizens are *lured* into motion.

The possibility of enjoying fresh air, bathing and playing opens up for other possibilities than the traditional public swimming baths which, to a larger extent, satisfy the organised sports' need for standard-sized lanes. And the close connection to residential houses and work places provides better possibilities for the public to use the new opportunities.

More nature

The reduction in the sewage discharged has also contributed to significantly improved living conditions for animals and plants.

New studies of the combination of seabed fauna compared to previous studies show a clear increase of both the diversity and the biomass. Species which are indicators for clean water have particularly increased in number. The spread at depth of bethnic vegetation has also increased significantly over the last ten years and today reaches the visibility depth in the entire port in parts where physical disturbances like propellers do not prevent vegetation. These improvements are particularly a result of the large reduction in the amounts of material in suspension discharged.

The smaller amounts of material in suspension in the water phase allow the light to penetrate further down the column of water so benthic vegetation can grow in greater depths. In Sydhavnen the sediment's content of organic material has been reduced by 50 per cent since 1990. In all likelihood, the increased diversity of the sea bed fauna is due to the improved oxygen conditions which are caused by the lower content of organic material.

The challenges ahead

After discharges of sewage have been reduced significantly and life in the Port is returning, the most important challenge remaining is the polluted sediment in the Port. In addition to this, climate changes will lead to more episodes with heavy rain and therefore more episodes with overflow of diluted sewage.

Polluted sediment at the Port

The sediment at the bottom of the port is polluted with a number of strong environmental toxins. So far they are bound to the sea bed in the Port, and only cause minor pollution in the fish and organisms living or feeding on the food in the water in the Port. On the other hand, plants and animals living in the sediment are polluted with environmental toxins, and benthic fish feeding on the animals and plants on the seabed are polluted to such an extent that it makes them unsuitable for eating.

This involves many different environmental toxins discharged over many years, including mercury and TBT.

TBT.

TBT is one of the most toxic substances added to the aquatic environment. Effects like malformation and gender change of several of the species of lower animals as well as impacts on immune systems in birds and mammals are directly attributable to TBT, which is released from antifouling paint for ships. TBT is primarily used on larger ships, as since 1989-1991 TBT has been banned from paints for leisure boats smaller than 25 m in most North Sea countries, including the Nordic countries, and since 1999 in the entire EU. Also from 2003, the EU has adopted to phase-out TBT for large ships with a ban against adding new TBT-containing paint in connection with subsequent dry-docking, and from 2008 TBT-containing paints must either be sealed or completely removed from all ships flying EU flags. TBT degrades very slowly in the sediment's oxygen-free environment, and can therefore pose environmental risks many years ahead.

Today the environmental toxins are bound in the sediment. However, there is a risk that the improved conditions for animals and plants on the seabed of the Ports will cause increased releases of the environmental toxins to the surrounding aquatic environment.

The City of Copenhagen is therefore considering what methods are the most appropriate for handling problems with toxic sediment. The possibilities range from leaving the sediment at the bottom of the Port to dredging it away for landfilling under safe conditions, or treatment before the sediment is deposited or dumped. The problem with dredging up, apart from the costs, is that there is a risk that the sediment is swirled around in the water so the environmental toxins are spread to the surrounding aquatic environment. At the same time, dredging up will destroy the regenerated sea bed fauna.

Climate change and more episodes with heavy rain

Climate change is expected to increase the frequency of episodes with heavy rain. We have already seen this trend. This will increase the need to expand the sewage tanks. At the same time it will increase the need to find more long-term solutions to the problems of handling the rainwater from Copenhagen's paved areas. There will be a need for increased cooperation with other municipalities located in the surrounding area to the sewers in the Port. The goal must be to reduce the amount of rainwater which needs to be drained off via the sewerage system as much as possible, just as was done in connection with the new urban areas built near the Port.

Results in relation to innovation and development

Intelligent wastewater tanks

In connection with investments to reduce pollution and create and satisfying aquatic environment a number of technologies developed within the last few years has been implemented. The storage volumes are a major part of the investments. The storage volumes are cleaned automatically, mechanical cleaning of the overflow water are implemented and bending weirs make sure, that the effect of the volume are fully optimized giving no unwanted surcharge. Real time control is used to control the performance of the basins locally as well as for the global control of the interaction between the basins and bigger pumping stations. Local cleaning of the combined sewerage overflow is used to reduce the amount of polluting particles and not the least bacterial pollution.

The warning system

The warning system has regularly been further developed since its inception. Today a three-dimensional model is being used instead of a two-dimensional model, the model's resolution has been improved, and a faster computer is now being used. Since the calculations are subject to some uncertainty, safety factors have been included in the assessment of the water quality which means swimming facilities are closed during an overflow for longer periods than calculations show to be necessary so that the water quality is guaranteed when bathing is resumed. All in all, the model contributes to faster and more precise calculations of bathing water quality. Ultimately, the model also leads to better municipal services, as the closing hours of the harbour swimming basins are reduced because the uncertainty in the calculations is becoming smaller.

Lessons learnt

- Reconstruction of old industrial ports in the centre of the city holds a great potential for improving the quality of life in the city, and creates rich outdoor life.
- It is possible to create an attractive and varying aquatic environment in ports that have been heavily polluted. Animals and plants quickly settle of the clean water once the pollution has stopped.
- The City of Copenhagen's long-term environmental goals with associated efforts to modernise the sewerage system have been necessary to implement cost-effective efforts.
- The warning tools have been a decisive and "cheap" precondition for the re-establishment of public bathing in the dock area.
- There are benefits in treating rainwater and sewage separately in new urban areas.
- Different municipalities in the same sewerage system often have different interests when money is being allocated for investments in sewerage systems. In a long-term perspective work should be towards common investment plans, but quick results are easiest to make if the municipality cashing in the profits of the investments can start on its own.
- A lively atmosphere by the port helps generate new jobs within the service sector in the form of cafés, restaurants, renting boats, kayak instruction etc. and a clean aquatic environment by the port helps raise the prices of real estate.

The Port was for many years used as a "rubbish bin" by the citizens of Copenhagen, its garages and enterprises as well as visiting ships. As the current in the strait between Zealand and Amager is relatively strong, the pollution was quickly taken away. From the mid 1800s when the city began to develop into an industrialised city of over a million inhabitants, pollution rose significantly, and in 1930 it had reached a level where public swimming facilities in the Port had to close for health reasons, and in 1960 the last bathing site in the Port closed. The Port was heavily polluted when the City of Copenhagen decided to change the use of Sydhavnen in 1989.

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