Historical overview of the Copenhagen sewerage system

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ABSTRACT

The Copenhagen sewerage system was established in 1857. Thus, in 2007 we celebrate our 150th anniversary. Previous to the establishment there were some years of discussion of the principle – combined vs. separate sewer network. Most of the sewer network we know today was founded 1860-1910. Until 1892 the contents of latrines were still collected and driven to the country for fertilization. The rest of the sewage was lead to the harbour, causing extreme odours and sedimentation of sludge. In the time the water closets were allowed to lead the wastewater to the sewer network, the sewage was collected in new pipes along the harbours, and only during rain there were spills from CSO. In the harbour, public baths were established, but because of the poorer and poorer water quality, the last bath closed in 1952. In the 1990s, a SCADA system was established and real time control introduced. Since then, RTC is an integrated part of managing the sewer network. In the same period, some major projects started with the aim of reducing the CSOs and large storage volumes were established. This resulted in the establishment of a public bath in 2002 followed by yet another in 2003.

KEYWORDS

Open sewers, sanitary conditions, closed sewers, intercepting sewers, large reservoirs, bathing.

INTRODUCTION

The extension of the Copenhagen sewer system has taken place at clearly delimited stages with each their specific target:

- The large sewers leading wastewater and rainwater into the harbour were constructed from 1860 to 1885 in order to improve the sanitary conditions of the city.
- The sanitary conditions of both the city and the harbour were improved when intercepting sewers were installed along the harbour from 1893 to 1903 to pump most of the wastewater into the Sound.
- The sewer system of the western part of Copenhagen was established from 1904 to 1920. The wastewater was treated biologically before the outlet at the marine recipient in the south of Copenhagen, and the plan was to merge all outlets in a joint treatment plant – Damhusåen - (at the outlet of the Damhus Brook to the southern marine recipient) and to lead a joint outlet sewer across the island of Amager to the Sound. These considerations took into account the recipient's capacity to receive the wastewater.
- Seeing that in general the recipients were unable to receive the wastewater, the Lynetten treatment plant in the north of the island of Amager was built and commissioned in 1980. The extension, including installations to remove nutrient salts

at the Damhusåen and Lynetten treatment plants, was planned and implemented during the period from 1987 to 1997. Sewer system plans now clearly allow for the capacity of recipients, and the environmental authority defines the requirements.

- A number of new reservoirs were built from 1994 in order to avoid or reduce wastewater discharge to marine and freshwater areas during rainfalls. The plants were dimensioned according to the specific requirements of individual recipients set out by the environmental authority. Thus the East Amager reservoir ensures that the requirement for bathing water quality can be met. It is the first time that this has been made a primary requirement. During this period, attention was increasingly directed to the sewer system's impact on ground water and on conditions in lakes and streams.
- From 2000, the frequency of CSOs to marine recipients has been defined in terms of bathing water quality. The timeframe for objectives concerning sewer rehabilitation and measures to meet a certain quality with regard to lakes, streams and marine recipients is 2009.

HISTORICAL BACKGROUND

Open sewers

In the 1850's, the population of Copenhagen lived behind King Christian IV's ramparts, which had been established more than 200 years earlier. Since then the population had multiplied by four or five, and in 1840 approx. 140,000 people lived in the city. In addition, it housed about 1,400 cows, 700 pigs and almost 3,000 horses. All traffic to and from the city had to pass through its four gates. The cramped space led to heavy overbuilding with a sanitarily harmful mixture of housing, slaughter stalls, stables, cowsheds and latrines. The properties were built on former dumping grounds. Far into the 19th century, Copenhagen's wastewater was discharged according to the same principles as in the 17th century. Improvements were few and quite inadequate. Only latrines were collected and brought to Kløvermarken in the isle of Amager in Copenhagen from where the contents were gathered in great barrels and transported by special trains to be used as fertilization outside Copenhagen (se photos). Until 1860, wastewater and rainwater in Copenhagen was led through deep, open sewers into larger outlets to the harbour and canals. Cesspools were installed at major outlets to retain a certain amount of sand and sludge. Because of the open sewers and the poor quality of the drinking water among other things, the sanitary conditions of the city eventually became disastrous. Even though, compared with present-day conditions, the amounts of wastewater were very limited; wastewater and other kinds of waste contaminated the harbour and canal water to such an extent that sludge had to be dredged from the bottom at regular intervals.

Closed sewers

As early as 1845, Mr Kabell, Lord of the Bedchamber, submitted the first plan for the concurrent construction of a modern water and sewer system to the Royal Danish Water Commission. The plan, which was not implemented, implied the introduction of lavatories. In 1847, the Royal Danish Water Commission proposed the inclusion of modern gas lighting in the overall project. In 1849, the Combined Committee set up by the Corporation of Copenhagen obtained the City Council's consent to arrange a competition for an overall plan for all three public utilities (water, sewerage and gas), but none of the proposed plans were

Photo 1. The latrine barrels are being emptied. Kløvermarken in Amager, 1901.

Photo 2. The latrine train. Just outside of Copenhagen, 1899.

eligible for the jury's approval in 1851. Paving inspector Lindberg had submitted a sophisticated forward-looking plan for a separate sewer system with lavatories. His plan was selected as a basis and upgraded with the proposal for a pumping station and outlets to the sea alone, which had been submitted by the Frenchman, Mr Marillier. Disagreement on the future sewer system delayed the decision for several years and made it impossible to install the sewer system at the same time as the other systems. The prefect, who turned out to have the most clout, was of the opinion that the night soil should continue to be collected, carted out and used as fertilizer and that consequently the installation of lavatories could not be allowed.

Photo 3. The latrine barrels have been cleaned and are ready for reuse. Kløvermarken in Amager, 1901.

A politically and technically acceptable solution for the sewer system had to be found. The new plan was presented in 1856 and adopted in 1857. Water inspector Colding prepared the plan. The plan also included the new urban areas outside the ramparts and was based on the principle of the combined sewer system. The plan was to establish a sewer system with a natural gradient from the parts of town situated on higher ground and with outlets to the harbour. The system was to be prepared for later installation of lavatories if required by the local authorities. The construction of Copenhagen's present-day sewer system began with the plan adopted by the City Council the 26th of October 1857. The decision-making process up to 1857 was highly dramatic and illustrates the struggle of opinions and power during a time of change.

The final implementation of the plan from 1860 to 1885 comprised a number of small

drainage areas with separate outlets to the harbour, the canals or the coast. The big deep-lying main sewer connected to a pumping station in Christianshavn, which was a precondition of the installation of lavatories, came to nothing at the time. The establishment of water closets was not made possible until 1897 - 50 years after this became compulsory in London.

So the technology was known and the many inconveniences to the population of Copenhagen caused by the decision could have been avoided. Transportation and removal of night soil came to be a major problem. At the same time, the many sewer outlets of wastewater from households, industry and slaughterhouses caused the harbour and canal conditions to deteriorate compared to the situation before the introduction of closed sewers. For long periods during the summer the harbour water constantly fermented. Large amounts of sludge therefore had to be dredged regularly and big parts of the city were affected by obnoxious smells.

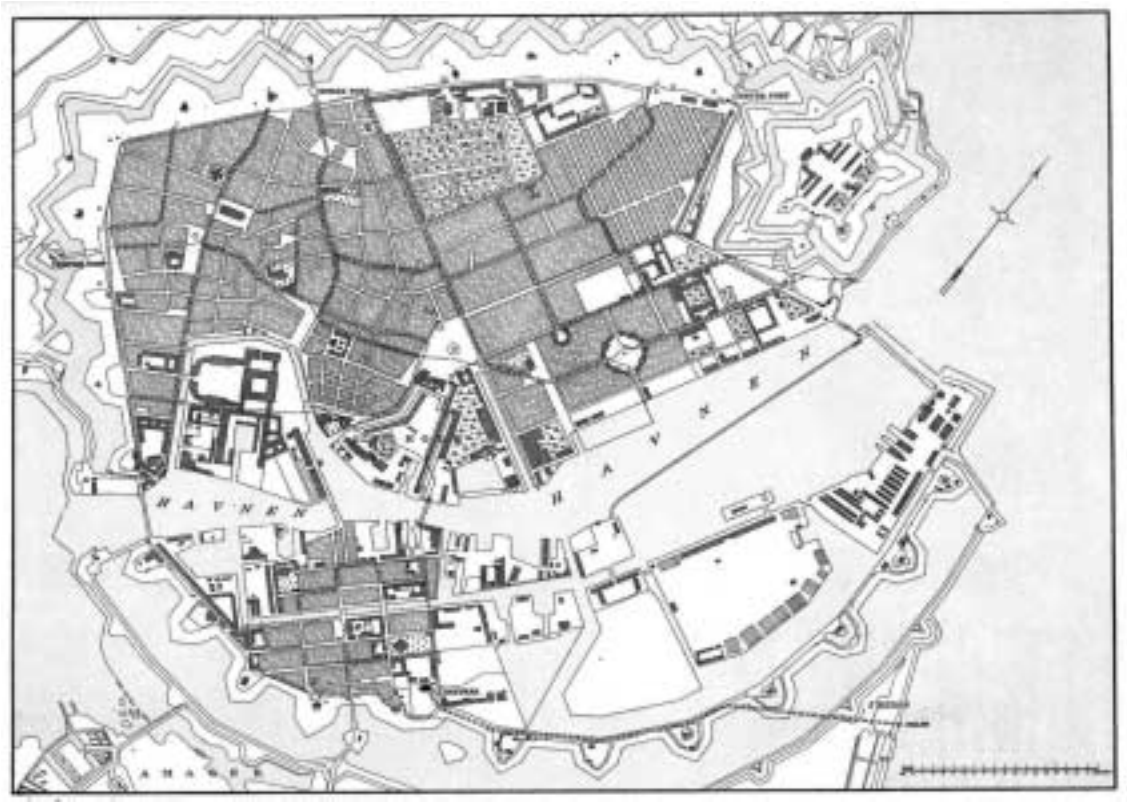

Figure 1. Separate system for Copenhagen 1853, which was not implemented.

The sewer discharge unavoidably affected seaside life in Copenhagen, which commenced with the establishment of the first public baths in 1785. Certain scepticism of the water quality must be the reason why the baths established in the inner part of Copenhagen Harbour in 1859 were moved to the cleaner waters of the southern marine waters. Shortly after the turn of the century, which saw the next major extension of the sewer system, harbour conditions apparently improved, and public baths were established at Gasværkshavnen, situated between the two former mentioned spots and remained in operation for 50 years.

Today it is important to remember that in those days no certain knowledge was available on pathogenic causes. The choice of system - the combined sewer system as opposed to the separate system originally adopted with a large majority by the City Council - was a necessary

compromise on which later improvements were successfully based. The question of which principle - the combined or the separate system - is the best has been the subject of discussion throughout the years, and it is hardly possible to come up with a univocal answer. Indeed the cholera epidemic came to an end, but that may have been due to better water supplies rather than the construction of sewers.

Intercepting sewers along the harbour

In May 1893, the Corporation of Copenhagen made the final proposal for cutting off wastewater from the harbour. After protracted debate in committee, the proposal was finally adopted in February 1897. Work was started immediately and completed in 1903. Thus the decision to introduce lavatories, which had previously been deferred, but which was clearly what the majority wanted, was finally made. As early as 1903, 2,500 water closets had been installed, and the number had increased to approx. 80,000 by 1916. However, approx. 30,000 night soil tanks were still in use in 1903. However, the Østerbro sewer system, which comprised a intercepting sewer from the north and one from the south, a pumping station and a temporary north-going pressure pipe to the outlet to the Northern bay of Copenhagen, were constructed as early as 1894-95. This was due to the fact that the sewer conditions of the harbour had to be in order before Copenhagen's free port could be constructed. As this meant that it would avoid costly dredging, the port made a substantial contribution - which was not unusual - of approx. 50% and a fixed annual operation contribution for a number of years. In 1915, after having considered separate discharge to the Sound, the pressure pipe was diverted to the south. The intercepting sewers were designed to drain off all daily wastewater, which would now include lavatory water. Furthermore, the sewers were dimensioned to transport future wastewater amounts caused by increases in the population. As it would be impracticable to include all rainwater, most of it was planned to be discharged to the harbour via auxiliary sewers with overflow structures. Therefore, it was decided to dimension the sewers to include the maximum amount of wastewater during the day and night plus double the amount of rain, so-called 1:2 distribution, which implied a drain capacity of three times the wastewater amount in dry weather. The water would be conducted from the intercepting sewers to a main sewer pumping station at Kløvermarksvej on Amager. The station was constructed on a municipal site centrally situated more or less opposite the centre of the then existing harbour. From the main pumping station the wastewater was pumped through a double pressure pipe to an outlet at a water depth of 11 metres and at a distance of 1,453 metres from the coast. This established the main principle for removal of wastewater from the eastern part of Copenhagen for the next 75 years: after treatment, the water was conducted through screens to a recipient which was presumed at the time to be able to absorb large amounts of wastewater without significant nuisance to the surroundings. Concurrently with the urban growth, two outlets to the Northern Bay of Copenhagen were constructed in 1902 and 1906. Because of these outlets, the public baths in this bay had to be closed down in 1932. During the period from 1938-1945, they were merged in a joint installation nearby (Strandvænget), where the wastewater was conducted through screens before being discharged to the Sound approx. 1,5 kilometres north of the pumping station outlet at Kløvermarksvej. South of the harbour along the east coast of Amager, a joint outlet was constructed in 1921. It was extended to 1,300 metres in the early 1930's and the wastewater was conducted through screens before discharge. In 1969, the outlet was diverted to the pumping station at Kløvermarksvej (the outlets are marked A, B and H in Figure 2 concerning the northern Bay, D: C and P concerning: Kløvermarksvej). When incorporating areas in the western part of Copenhagen in 1900 and 1901, a different strategy had to be selected due to the north-south watershed, cf. Figure .2 (map from 1914). During the period from 1904-1920, three outlets to the southern marine recipients were established with preceding biological

treatment (marked F, J and K in Figure 2). They were later combined at a joint treatment plant at the Damhusåen outlet (F) and the discharge from here was led into the Sound. This development was completed on 9 September 1996.

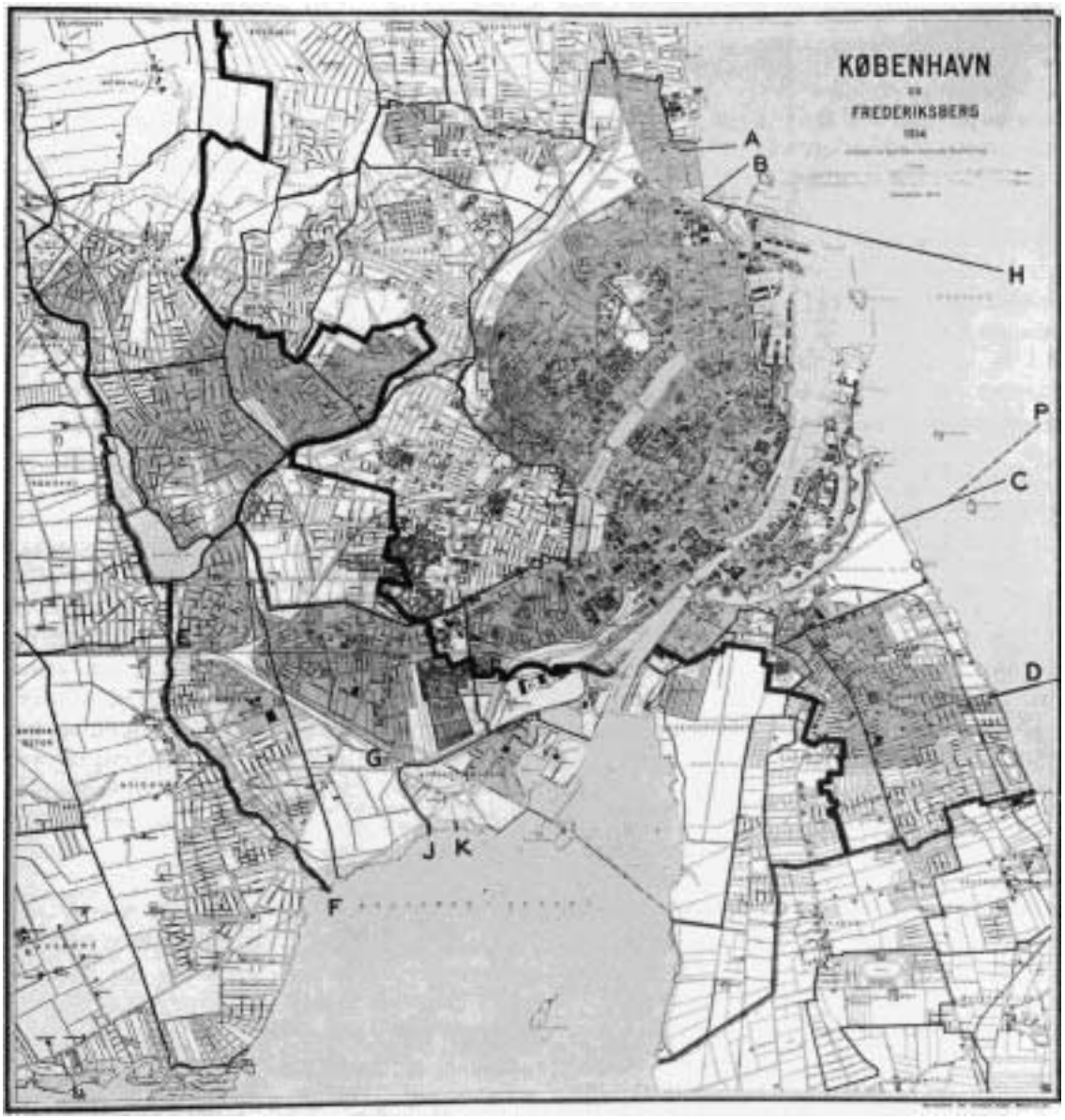

Figure 2. Watersheds.

Treatment plants

As early as 1931-32, comprehensive streamlining analyses were conducted and the bacteriological and hydrological conditions of the Sound were registered, based i.a. on complaints of unsatisfactory bathing water at the beaches of Bellevue and Amager. This resulted in the above-mentioned changes to the installations at the Northern Bay and the pumping station at the east coast of Amager. In 1949, supplementary analyses were conducted to determine the final location of the wastewater outlet from the pumping station at Kløvermarksvej. Conditions were satisfactory according to an article in the City Engineer's 1951-52 report, but it might be necessary at a later stage to provide the outlets with extensive treatment devices if the outlet at 1.5 km from the coast were to be maintained. In 1964, new flow analyses were conducted with a view to determining the outlet location of the

Damhusåen treatment plant. Provided that the wastewater was biologically treated, the analysis confirmed that discharge at 1.5 km from the coast was acceptable. The eastern outlets were merged at the Lynetten treatment plant, which was put into operation in 1980. The Aquatic Environment Plan from 1987 led to requirements to include "N & P" (nitrogen and phosphorus) in the treatment. In September 1990, it was decided to extend both the Damhusåen and Lynetten treatment plants within the Lynettefællesskabet I/S area. Commissioning of the Damhusåen treatment plant was started on 9 April 1996 and direct pumping to the Sound on 9 September 1996. For practical reasons, the Lynetten treatment plant followed a little later. The joint Lynetten treatment plant was inaugurated on 29 August 1997. Now all outlets are to the Sound.

The large reservoirs

Extending the treatment plants led to the best possible treatment of daily wastewater, including a certain amount of rain. As mentioned before, the 1897 project included the discharge of a certain amount of diluted wastewater to recipients. The amount was later considerably reduced. In July 1997, a 30,000 m^3 reservoir was commissioned in the former free port, followed by further pipe reservoirs along the harbour. A reservoir in Sydhavnen (15,000 m^3) just south of the inner harbour with accessory reservoir pipes and comprehensive online management of water amounts using gates and meters improved conditions in the inner harbour, and the East Amager reservoir (40,000 m^3) ensures stable bathing water quality which formed part of the plans for a major extension of the Amager beach. The natural surface flow to freshwater recipients was reduced concurrently with the increase in paved areas. At the same time, many years of overflows have resulted in generally poor environmental conditions of freshwater recipients. Therefore, a reservoir along the Utterslev Marsh (limiting to the northern neighbouring municipalities) was supplemented with a root zone system in 1998 allowing the mixture of wastewater and rainwater to be treated before discharge to the marsh. This development requires data retrieval and systems management and consequently, the SCADA systems are being upgraded significantly.

Copenhagen's current sewer system

The City of Copenhagen covers an area of approx. 9,000 hectares and has a population of approx. 501,000. The population grows considerably in the daytime. The sewered area now totals approx. 6,800 hectares of which 90% is covered by a combined sewer system and the rest is covered by a separate system. Approx. 2,200 hectares are situated in open areas with no need for sewers. Copenhagen has a total of 1,100 kilometres of main sewer and approx. 300 kilometres of service pipes. Rainwater and wastewater are conducted to the Lynetten and Damhusåen treatment plants. They also receive rainwater and wastewater from areas in neighbouring municipalities. Rainwater and wastewater from households, businesses, institutions, etc. are conducted to street sewers through 35,000 service pipes, while rainwater from the streets is supplied through approx. 20,000 gully gratings with accessory service pipes. The annual amount of wastewater from Copenhagen to the treatment plants is estimated at approx 32 million m^3, excluding contributions from neighbouring municipalities. The total annual amount of treated rain- and wastewater in the two treatment plants is of 90-100 million m^3. 6 rain gauges have been installed in Copenhagen as part of a nationwide network. Rain gauge statistics for Copenhagen show that the annual average rainfall is approx. 660 millimetres corresponding to a rainfall of approx. 45 million m^3 over Copenhagen. In addition, there are 43 overflow structures in action between 0-33 times a year – the average discharge is 13.7 times annually. However, a distinction should be made between areas where reservoir and overflow structures have been established recently (after 1994) - notably the harbour areas - and areas where the overflow frequency has not yet been reduced. In most

harbour areas the water quality now meets the requirements for bathing water. Thus two public baths have been established in Copenhagen Harbour – the first one in 2002 and the second one in 2003. They are open during the summer, connected to an alarm system that closes the baths in case of CSOs to the harbour and are frequently used by Copenhageners. Similarly, the beach area east of Amager was awarded the EU Blue Flag. A beach park was established in 2004-2005 increasing the recreational value of the area. A planned rehabilitation of the sewer system was started in 1982. By the end of 2004, a total of 780 kilometres or 73% of the main sewers had been TV inspected. Of those, 250 kilometres were rehabilitated as assessments of their condition indicated that they had exhausted their service life.

Copenhagen's future sewer system

In the years to come, emphasis will still be on achieving bathing water quality in the harbour areas that have not yet achieved this. Cases in point are the northern part of Copenhagen, where reservoir capacity is currently being established to reduce overflows to the Svanemølle Bay, and the south-western part of Copenhagen comprising an extended system of streams flowing into a harbour and habitat area of great recreational value. The planned rehabilitation will continue so that by 2009 all pipes will have been TV inspected. Defect pipes will be rehabilitated immediately. The rehabilitation will continue after 2009, at which time it has been 28 years since the first sewers were rehabilitated. The sewer system of the new Ørestad district of Copenhagen is and will be a separate system. The water is divided into three fractions: wastewater, rainwater from contaminated surfaces (roads, parking areas, etc.) and rainwater from clean surfaces (roofs, parks, etc.). The wastewater will be led to the treatment plant while the rainwater from clean surfaces will be used recreationally in the established canals. The contaminated rainwater will be treated in a specially designed rainwater treatment plant before being led into the canals. The technology is named dual porosity filtration and runs as a pilot project in Ørestad in 2005. The future townscape of this district will include open drains. However, unlike the situation in the Copenhagen of Christian IV, they will only be filled with uncontaminated rainwater from roofs...

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