Enhanced local treatment of combined sewer overflows enabling the implementation of the Water Framework Directive

Une amélioration du traitement local des rejets des déversoirs d'orage permettant l'application de la directive-cadre sur l'eau

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RESUME

Trois modèles en grandeur réelle ont été construits pour étudier les types de déverse des réseaux unitaires : 1) déverses d'un petit bassin versant vers un petit ruisseau, 2) déverses d'un bassin versant plus grand vers une eau réceptrice plus importante, et 3) déverses vers des eaux balnéaires en mer. Cette contribution donne une description des technologies proposées ainsi que les résultats d'un programme de mesures pour tester les modèles en grandeur réelle. Une analyse économique et écologique indique qu'aujourd'hui on dispose de technologies de traitement pour les déverses unitaires supérieures aux technologies traditionnelles reposant sur des bassins de stockage.

ABSTRACT

Three full-scale facilities are constructed to study typical types of CSO discharges : 1) Discharges from small upstream catchments to small watercourses, 2) Discharges from larger catchments to larger surface water, and 3) Discharges to marine coastal waters where bathing is permitted. The paper outlines the proposed technologies and the results of a measurement programme to test the facilities in full scale. An economical and environmental assessment of the results indicates that in some cases enhanced clarification technologies are now ready to be implemented in minimizing the adverse effects of CSO discharges compared to traditional detention basins

KEYWORDS

Combined sewer overflows, health, enhanced treatment, water framework directive.

INTRODUCTION

Intermittent discharges from combined sewer overflows can prevent the surface waters from having an acceptable status as defined in the Water Framework Directive. One of the reasons is the high content of pollutants. The combined sewer overflows must therefore be studied with the intent of minimizing the adverse effects to an acceptable level. If space permits large retention volumes may be constructed or the water may be filtered or treated in wetlands (Marsalek *et al*, 1999, Färm, 2003). These methods use a lot of space and are less suitable for areas that are already fully developed. Further, the widespread use of wetlands in urban drainage is believed to be part of the reason for the rapid spread of West Nile Virus in North America. Therefore treatment options should be considered as an alternative to storage wherever possible.

Simple treatment such as the Vortex separator is in general not sufficient in order to reach the objectives of the Water Framework Directive. Brashear *et al* (2002) define a class of treatment processes which they denote Enhanced Clarification Technologies. These are technologies where the basic clarification processes are enhanced in different ways, e.g. by lamella separators and UV-disinfection. However, because of the relative novelty of the application of many of these technologies to rainwater, there is a decided lack of full-scale applications on which to judge the efficiency. The paper reports the results of such full-scale applications aimed at different types of discharges.

1 DESCRIPTION OF FULL-SCALE FACILITIES

Three full-scale facilities has been constructed and their performance evaluated, one in each of the cities Copenhagen, Odense and Aarhus. The facilities represent three typical situations with regard to CSO discharges. For each test site anticipated suitable solutions have been developed aimed at solving the environmental aspect in question. The evaluation is therefore based on two sets of criteria: 1) Efficiency with respect to removal of typical pollutants, and 2) Efficiency with respect to improving the surface water in question. Both evaluations will be discussed in the present paper, but most emphasis will be put on the first criteria.

The typical types of CSO discharges studied in the project are (See Figure 1):

A. Discharges from small upstream catchments to small watercourses. The tested solution consists of a novel CSO-structure with enhanced hydraulic conditions followed by a structure on the outlet pipe containing a lamella separator.

B. Discharges from larger catchments to larger surface water. The tested solution consists of a hydraulic optimization of a storage tank by dividing it into a first flush chamber followed by four parallel channels used to compare two types of lamella separator and a Turbofloc system with a sedimentation tank equipped with scrapers and a sludge pit. The total volume of the tank is 7400 m³.

C. Discharges to marine coastal waters where bathing is permitted. The tested solution consists of an advanced filtration system consisting of three consecutive filters with smaller and smaller mesh sizes (2 mm, 0.1 mm and 0.02 mm) followed by a UV-disinfection plant. The plant is designed for 500 l/s.

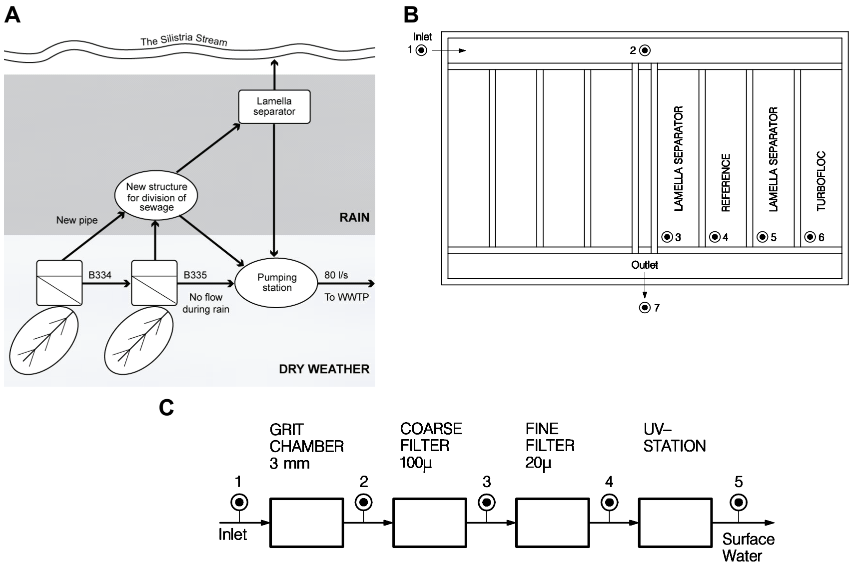

Figure 1. Outline of the demonstration facilities. a) Aarhus, b) Odense, and c) Copenhagen.

2 RESULTS OF THE MEASUREMENT PROGRAMME

The measurement programme encompassed a large number of parameters, including NPo compounds, metals, PAHs, *E. coli* and patogens. In the present paper results only a few pollutants are discussed, mainly suspended solids and *E. coli*. The project website contains more detailed reporting of all of the measured pollutants (www.cowiprojects.dk/lotwater).

The conclusions with respect to the efficiency of each of the full-scale facilities are presented below.

2.1 Treatment efficiencies of demonstration facilities

2.1.1 The demonstration facility in Aarhus

There is a clear reduction of the amount of pollutants that are discharged into the receiving water. Compared to the status situation the measurements indicate a reduction in both quantity and concentration levels. The discharges have in fact been reduced to a level where the lamella separator is not efficient and also the effect of the new CSO structure is rather low, see Figure 2. With the present layout the lamella separator is not necessary because the discharges occur after the first flush has occurred and only when the sewage is diluted substantially, with a content of sewage below 5 %.

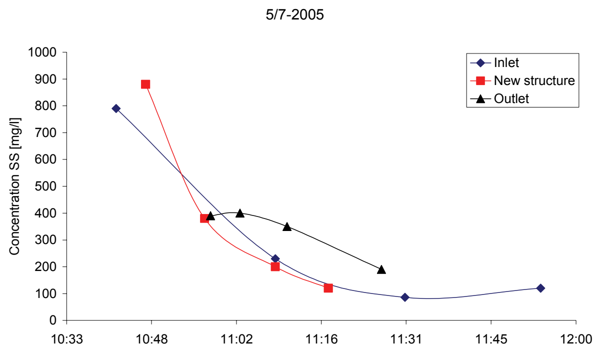

Figure 2. Variations of koncentrations of suspended solids throughout a typical event.

2.1.2 The demonstration facility in Odense

The overall performance of the detention basin has improved. Measurements carried out prior to the renovation of the basin indicated a reduction discharged mass of COD of approximately 54 %, whereas the retained mass of COD is now calculated to be approximately 63 %, corresponding to an increased treatment efficiency of 17 %.

The main reason for the increase in efficiency is apparently due to the hydraulic optimization of the demonstration facility. Installation of a first flush volume and ensuring equal distribution of the hydraulic loading to the remaining four channels give a much better chance of avoiding re-suspension than the original design did.

Comparison of the new treatment technologies in the second half of the demonstration facility indicates that there is not much difference between the treatment options. The best treatment efficiency is achieved by installing a rather large lamella separator at the end of the channel using a v-notch as overflow weir. Installation of a lamella separator at the inlet of the channel as well as using the TurboFloc system is no better than using the standard technology from the last channel, i.e. the use of baffles, a sludge pit and scrapers.

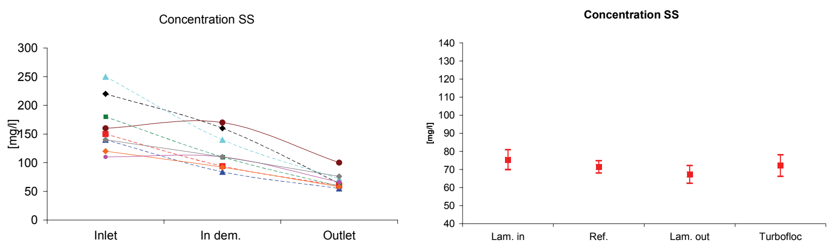

Figure 3. Analysis of SS. The figure to the left indicate the treatment efficiency over the entire plant while the figure to the right indicate the relative performance of the four treatment processes tested in the second half of the facility. The best treatment is obtained using the lamella separator in the outlet, followed by the tank with scrapers and a sludge pit.

2.1.3 The demonstration facility in Copenhagen

The demonstration facility in Cophagen is much more complicated than the other plants. Therefore supplementary indicators for success were defined, primarily the following:

- Quick start
- Stable operation
- Efficient removal

Based on the results it appears that the filters work well with respect to the first two indicators. At most of the events the design flow is reached quickly and the flow measurements in general indicate a stable operation. However, the outlet concentrations of suspended solids are higher than anticipated although the inlet concentrations are lower than the design values. The full scale tests have shown a removal rate of suspended solids of 25% in the first filter and 13% in the second filter. Based on pilot-scale tests the anticipated removal rate was expected to be approximately 60-75 %, see Figure 4.

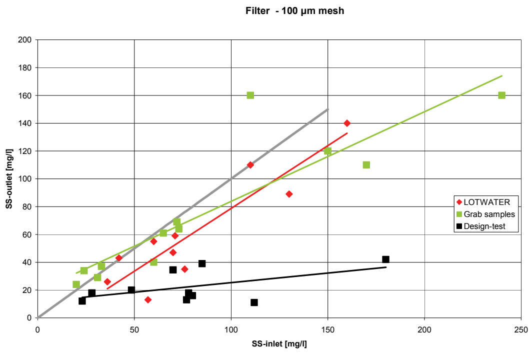

Figure 4. Removal of SS through the first filter with a mesh of 200 µm. Results from the pilot scale studies, flow-proportional sampling (denoted LOTWATER) and grab samples are shown.

The demonstration facility in Copenhagen has a very efficient removal of *E. coli* when the facility is running steadily. Several grab samples indicate less than 1 *E. coli*/100 ml in the outlet. However, quite often there has been a poor removal during part of the time of the events. This is why none of the events reaches a treatment efficiency that enables an average concentration in the outlet of 500 *E. coli*/100 ml on average during an event, the original design criteria. The results are presented in Figure 5.

The reason for this is most likely due to difficult operation of the facility and that commissioning of the electrical part of the demonstration facility took place during part of the measurement campaign. Therefore more stable operation is expected to be possible in the future. Before the construction it was assumed that the start up time was 10 minutes but the measurements indicate that the start up time is longer. In summary, it is believed that the design criteria can be met if the following changes are implemented:

- The removal of suspended is increased or the UV-dose is increased
- The flow rate should be minimized during the start-up phase in each event.

Finally, it should be noted that the plant is difficult to control and it takes highly skilled and motivated personnel to operate it.

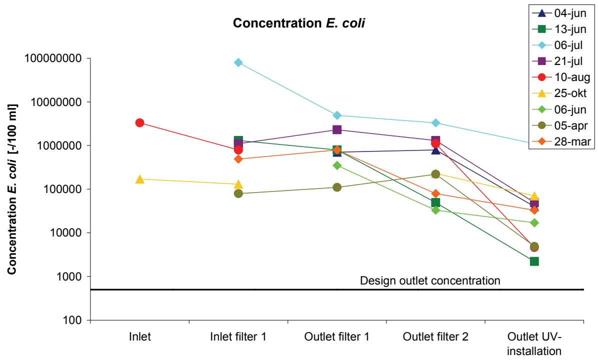

Figure 5. Concentration profile of E.coli throughout the demonstration plant in Copenhagen. Note the log-scale on the *y*-axis.

2.2 Achievement of environmental goals

2.2.1 Small watercourse

The biological index is expected to be the main indicator of the improvement of the stream. The biological index was measured at three locations, one upstream and two downstream (50 m and 350 m, respectively). The ecological status was very high before installation of the demonstration facility, i.e. meeting the expected future criteria of the Water Framework Directive.

However, even though the quality in the stream was higher than anticipated at the beginning of the project, it seems as if the quality at the station 350 meters downstream has improved in the project period despite the fact that an accidental discharge of sewage occurred in 2005 which decreased the upstream water quality. No other external parameters have been found which could influence the biological index and therefore it is concluded that the most likely reason for the improvement is the installation of the demonstration facility.

2.2.2 Large watercourse

The demonstration facility in Odense discharges to Odense River, which is one of the largest rivers in Denmark. Throughout Odense more than 60 CSO outlets discharge to the river during heavy rain. Enhancing the treatment efficiency at one of these points of discharge may be identifiable, but is not expected to be sufficient to solve the problem, given that CSO discharges is a problem.

It is concluded that the improved treatment efficiency of the demonstration facility in Odense probably is the reason why there is a tendency towards better chemical status in the river with respect to suspended solids and *E. coli*. However, the changes are not significant and they may also be due to quite different hydrological conditions between 2004 and 2005. The impact of constructing the demonstration facility is also difficult to assess because the river is influenced by other wet weather discharges, both urban and rural.

2.2.3 Bathing water in the surface water of Copenhagen

The measurements from the marine surface water in Copenhagen show the microbial water quality has improved, especially in dry weather. It is still questionable whether the bathing water criterion is met given that the current layout is used. Therefore other measures are currently being implemented to ensure that the microbial water quality will comply with the Bathing Water Directive in the future. This also includes further optimization of the demonstration facility.

3 GUIDELINES FOR FUTURE DESIGN OF CSO-STRUCTURES

Based on the results from the measurement programme and the cost of establishing and operating the demonstration facilities it is possible to assess the cost-efficiency of the demonstration facilities relative to other measures that could be implemented.

At the Copenhagen site the following measures were judged to be realistic:

- Construct the demonstration facility
- Construct a small detention basin using the available area as efficiently as possible. The detention basin will have a volume of up to 1000 m3.
- Construct a large detention basin purchasing urbanized areas at market prices. The nominal volume should be approximately 10.000 m3.

As shown on Figure 6 the Copenhagen demonstration facility is not cost-efficient with respect to COD. However, the demonstration facility provides the most efficient removal of COD relative to the area that are available. Currently purchace of urbanized areas are not politically feasible in Denmark.

Further, calculations based on removal of E. coli shows that the demonstration facility is very cost-efficient with respect to this parameter (€43/10^{12} *E. coli* compared to approximately €70/10^{12} *E.coli* for solutions based on detention basins).

For the Odense demonstration facility Figure 6 illustrates that the demonstration facility proves to be a solution that is cost-effective. Further, the optimization of the hydraulic features of the detention basin alone provides more removal of COD than establishing a further 1000 m^3.

Due to the limited efficiency of the demonstration facility in Aarhus the cost-efficiency has not been calculated. The demonstration facility might have been cost-efficient given that the emissions had been more frequent and had contained more of the total pollutograph.

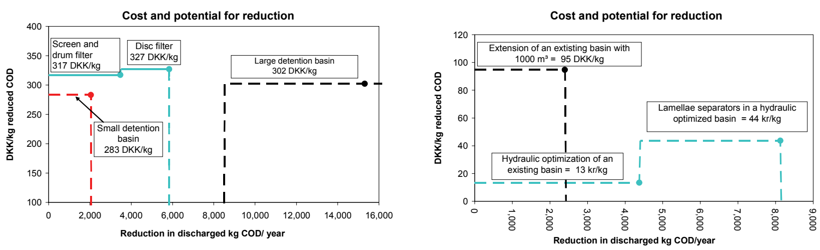

Figure 6. Evalutation of cost-effficiency with respect to removal of COD. With respect to this parameter the Copenhagen demonstration facility is not cost-efficient whereas the Odense demonstration facility is very cost-efficient .

Based on the overall examples and further calculations the following conclusions are made:

- Hydraulic optimization of basins is very cost-effective
- Lamellae separators are sometimes cost-effective in combination with basins. Their removal is however limited by a lower limit. This will in practice limit the use of this measure
- The tested filters are not cost-effective to detention basins when compared to traditional NPo compounds. However, the filters are the most efficient way to remove pollutants when only a limited area is available.
- Establishing of UV-disinfection to remove E. coli is cost-effective compared to building of retention basisns

Further calculations on typical situations will be carried out. This will enable more generally applicable guidelines for the use of enhanced clarification treatment options.

4 CONCLUSIONS

The testing in full scale of the suggested technologies at the demonstration facilities has yielded important information with respect to enhanced clarification technologies. Some of the technologies perform quite differently than anticipated based on pilot test studies.

Nevertheless, the results indicate, that all of the three demonstration facilities are superiour solutions when compared to traditional design and/or has improved the environment considerably. As such it must be expected that the use of more advanced technologies will be more widespread in the future.

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