Session 6: WFD and water quality planning

INTEGRATED WASTEWATER CATCHMENT MODELLING AND PLANNING IN ODENSE, DENMARK

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Introduction

This paper summarises the on-going programme of work being undertaken by CH2M HILL for a Danish water utility called VCS Denmark[1]. VCS own and operate the water and wastewater infrastructure in the City of Odense, Denmark's 3rd largest city (Figure 1).

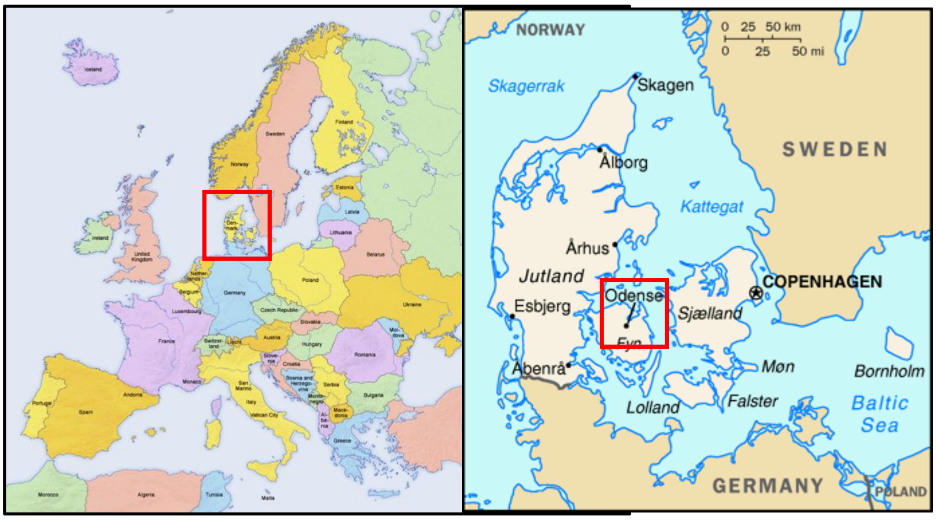


Figure 1 Location of Odense, Denmark

VCS Denmark is an advanced and forward thinking utility with as key guiding principles to:

- comply with legislation and regulation;
- deliver maximum value for customers;
- be socially responsible;
- protect human health, the aquatic environment & sustainable development;
- make investment decisions for the long term;
- support and participate in R&D;
- be a local, national and international role model.

Odense has a population of c. 300,000 and is served by three wastewater treatment plants (WWTPs) and a combined and separate sewer network. The Odense River and tributaries receive polluting discharges from the WWTPs, stormwater outfalls and over 100 combined sewer overflows (CSOs). The river is a salmonid fishery with a target to achieve Good Ecological Status under the Water Framework Directive.

VCS has described a vision for wastewater treatment and sewerage for the 2030s. The vision set outs objectives to:

[1] http://www.vcsdenmark.com/

- prevent frequent flooding of streets and basements;
- ensure compliance with WFD standards for biology and water chemistry by addressing wet weather CSO discharges;
- be prepared for extreme flooding events;
- develop blue-green infrastructure to deliver multiple benefits;
- strike the right balance between grey and blue-green infrastructure;
- make WWTPs net energy producers.

The objectives need to be delivered in the face of considerable pressures, which will be familiar to all wastewater utilities. These are the combined effects of climate change, population growth, urban development and the affordability of water bills. Balancing long-term objectives with the pressures requires careful planning and a partnership approach between the utility and the municipality. The municipality also acts as the environmental regulator.

To date the Regulator has required that CSOs in Odense be improved in a particular manner, increasing pass forward rates and limiting the annual volume of spills through the provision of storage. Typically, the annual spill volume is designed to not exceed 250m^3 per hectare of impermeable area draining to the CSO and spill frequency is limited to five spills per year. This rule has resulted in the construction of a number of large (> 10,000 m^3) storage tanks in the city. There are concerns that this policy is unaffordable and risks the efficient operation of the high technology and showcase Ejby Mølle WWTP when large volumes of dilute sewage are transferred to treatment rather than be spilled to the river.

Modelling and planning tools

CH2M HILL is supporting VCS Denmark establish a long-term strategy for investment in the Odense wastewater system. The WEST[2] integrated modelling platform has been used to construct an integrated model of the combined sewer (collection) network, three WWTP, surface sewers and river network. Figure 2 is a simplified example of an integrated system represented in WEST.

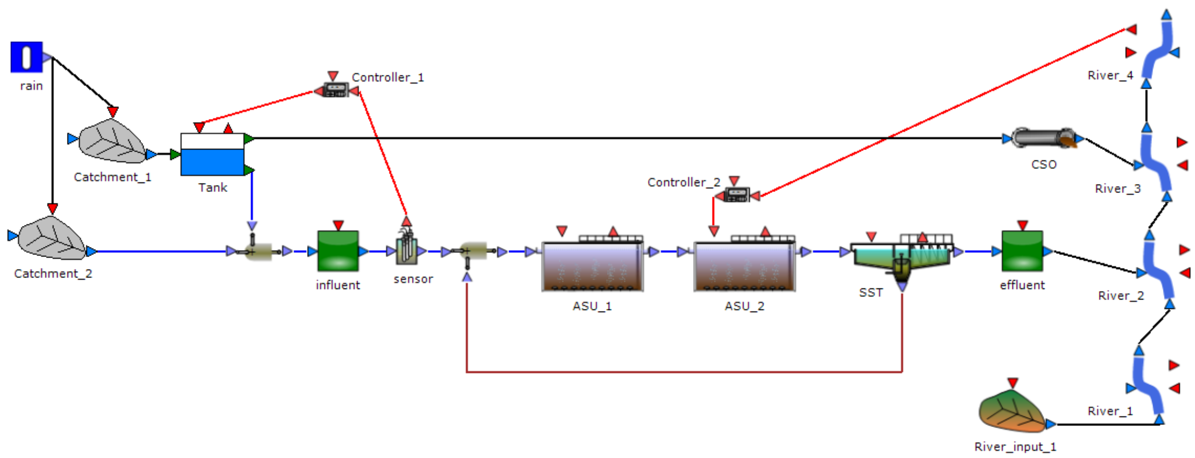


Figure 2   Example integrated wastewater and river model in WEST

[2] http://www.mikebydhi.com/products/west

The model is used (in continuous dynamic simulation) to compare river quality with UK type Urban Pollution Management (UPM) Fundamental Intermittent Standards (FIS) (FWR 2012) for unionised ammonia and dissolved oxygen. It is then used to test water quality outcomes of different management strategies using grey and blue-green technologies. The integrated model can also report on the operating costs of the system as a whole including sewage pumping stations and treatment processes. Initial model results are being used to design a continuous water quality monitoring programme which will be used to further validate the model through 2015.

For further information on the models, tools and approach adopted here, the reader is referred to publications regarding a similar project in the Netherlands, which is in a more mature stage as it started some years ago: Benedetti et al. (2013a), Benedetti et al. (2014), Langeveld et al. (2013a), Langeveld et al. (2013b) and Langeveld et al. (2014). A review on integrated modelling techniques in general can be found in Benedetti et al. (2013b).

Collection system

A pre-existing hydraulic model of the combined and surface water sewer system for Odense existed in the MIKE URBAN platform. The system was re-conceptualised to have only one catchment with runoff generation for each CSO, connected to the river and to the downstream parts, i.e. other catchments or main transport pipes, also modelled with a single tank; on-line and off-line storage tanks are also included. The resulting schematic arrangement of CSOs is represented in Figure 3.

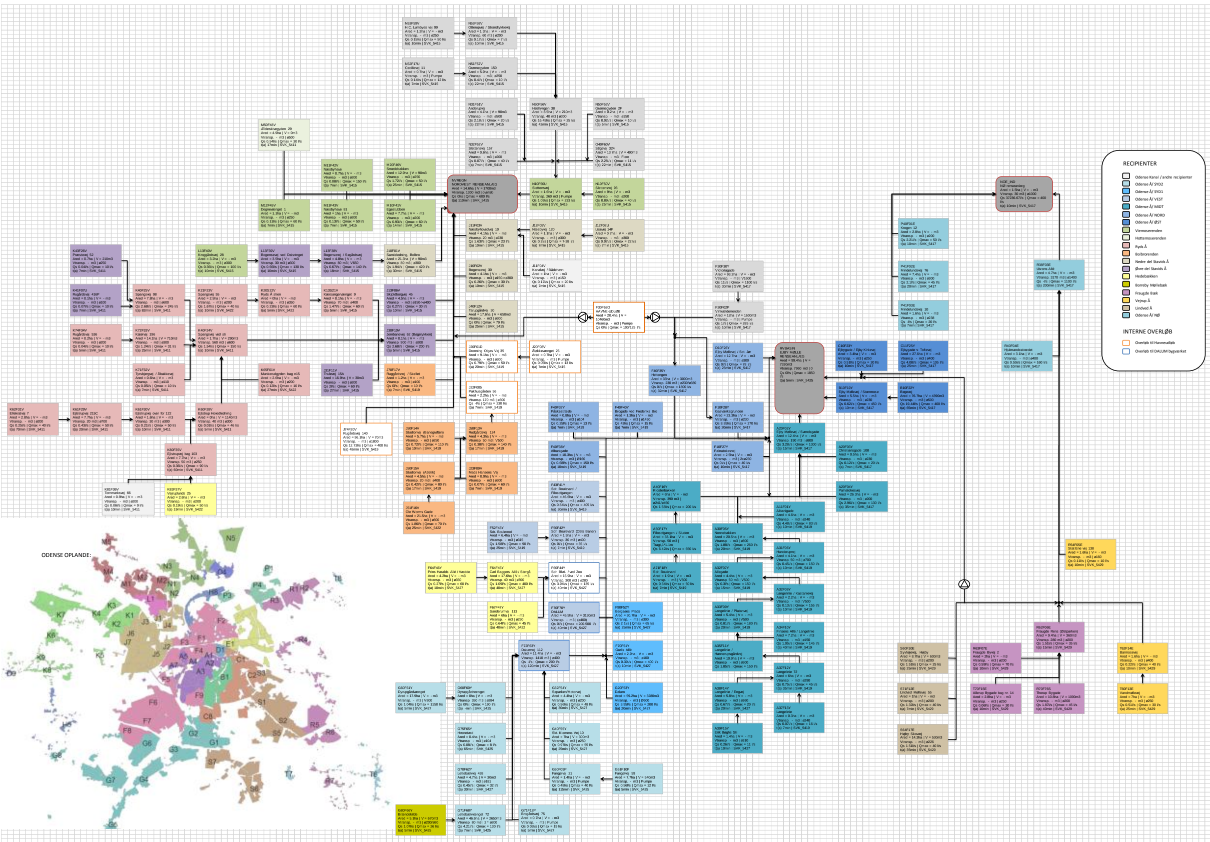


Figure 3 Schematic of CSOs in Odense.

Dry weather flows are generated as a function of inhabitants and their water consumption, industrial flows, infiltration rate, daily and seasonal profiles.

Wet weather flows are generated in the model by applying a 5-year long spatially variable (8 gauges) rainfall timeseries. Pumping costs are computed for the major pumping stations.

Sewer flow quality is generated for dry weather by using average concentrations and daily profiles, and in wet weather by accumulation/wash-off for particulates (COD, TSS) and fixed event concentrations for solubles (NH_4, PO_4). Routing of pollutants in the sewer includes sedimentation and resuspension of particulates.

In total, there are 124 CSOs and 60 surface water outfalls represented.

The network of tanks was then incorporated within the WEST environment and model performance validated against simulations from MIKE URBAN. Figure 4 compares WEST and MIKE-URBAN flow timeseries. Figure 5 shows the computed pollutant concentrations generated in the collection system model that form the WWTP influent for the larger Ejby Mølle WWTP.

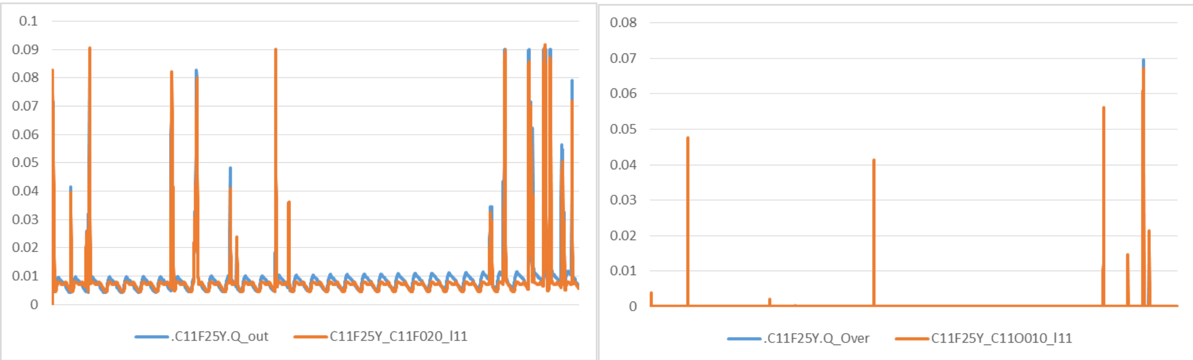


Figure 4 Example of pass-forward flow (left) and overflow (right) for one catchment; one month with 10-minute time-steps; unit on y-axis is L/s; blue is for WEST, orange for MIKE URBAN.

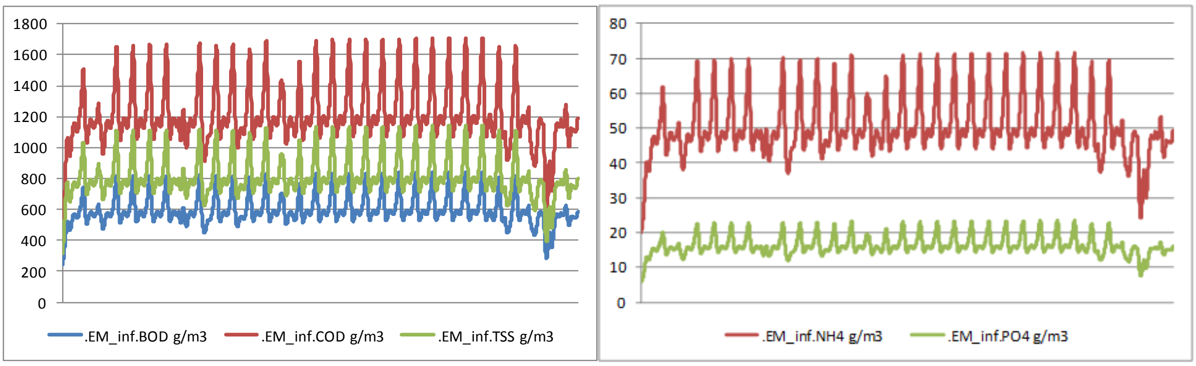


Figure 5 Influent concentrations of a WWTP; one month with 10-minute time-steps of WEST simulation; unit on y-axis is g/m³

WWTPs

Plants are modelled including all units of the wastewater treatment line, from primary settling to activated sludge to secondary settling, including all controllers for aeration and recycles. Activated sludge model No. 2d (ASM2d) was used for bio-chemical processes.

For the Ejby Mølle WWTP, a model in BioWin was slightly simplified in its spatial and process detail, while the other two plants were directly implemented in WEST.

Costs are computed in the model for aeration, sludge treatment (including energy generation from anaerobic digestion), pumping and chemicals.

Figure 6 illustrates a timeseries of final effluent concentrations.

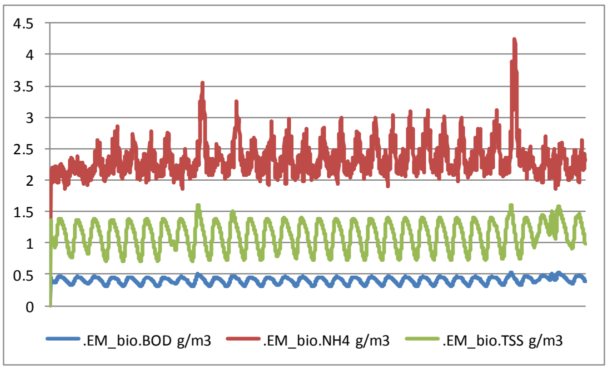


Figure 6 Effluent concentrations of a WWTP; one month with 10-minute time-steps of WEST simulation; unit on y-axis is g/m³.

River system

An 80 km network of river channels is included in the WEST model, which receives flow from headwaters, CSOs, surface water outfalls and 'diffuse' inputs. The network is represented through a series of tanks representing trapezoidal sections of river. Data for channel slope and geometry were taken from existing hydraulic models and site inspections. The river model is validated against flow gauge data at two locations.

The water quality model includes processes for DO (consumption by 5 types of BOD and reaeration), for nitrification and algae activity. Figure 7 is an example of modelled river pollutant concentration timeseries for one river reach.

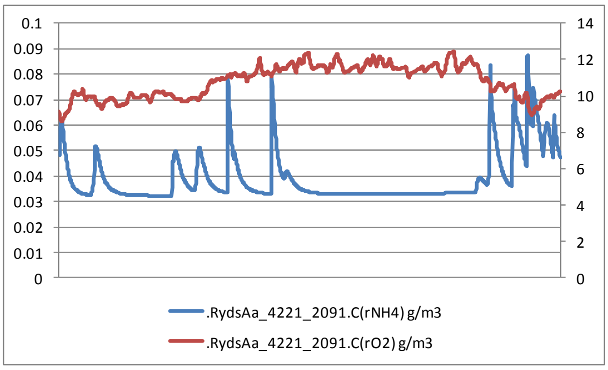


Figure 7 Concentrations (g/m³) in one of the river sections; one month with 10-minute time-steps of WEST simulation.

Initial Results

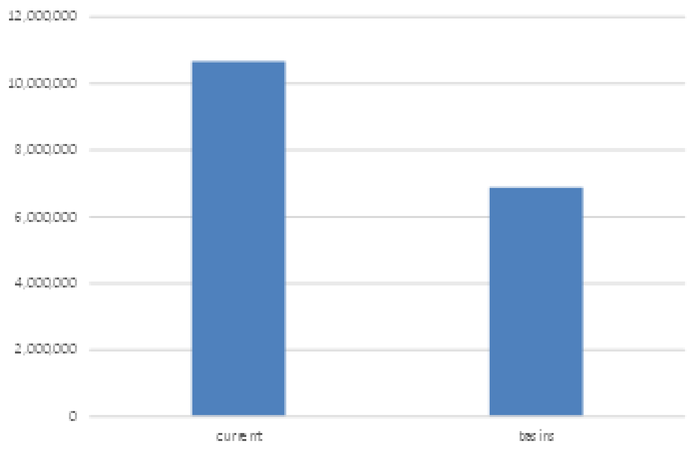
At the end of 2014, the integrated model is operable and predicting sensible responses during wet weather in WWTP final effluent, at CSOs and in the river system. Examples of the dynamics that are represented are illustrated in the Figures above. The stable and proven WEST platform provides a fast simulation. On standard office hardware the 5 year simulation takes 3.5 hours to complete.

In 2015 a programme of river water quality data collection will commence that will enable further calibration and validation of in-river processes. Meanwhile, the un-validated model is being used to engage with the Regulator and develop different strategies to be included in the long-term plan to deliver 2030 objectives.

As an example of the types of measures that can be tested with the model, two scenarios where compared with the current situation:

- Scenario 1: 34 new CSO storage tanks with volumes between 20 m^3 and 4,500 m^3, with total volume 23,385 m^3
- Scenario 2: green roofs on all roofed area in four catchments with CSOs discharging into small tributaries

Regarding Scenario 1, it can be noted in Figure 8 below that the presence of storage basins significantly reduced the total overflow volume in the whole system. When looking at the water quality in the reported river reach, it is clear that DO sags have reduced with positive impact on the classification. As for NH_3, it appears that the number of exceedances have increased (but remain within good water quality classification). This can be explained with the fact that the reported reach is located just downstream of one of the two smaller WWTPs, and that the solids stored in the basins are no longer discharged with the CSOs but conveyed to the WWTP, where the additional COD and TSS reduce the SRT and nitrification capacity of the plant, therefore increasing the NH_4 effluent load.



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1	1	1	1.7	1.3	0.2	1	1	1	1.7	4.5	0.2
1	1	1	0.0	0.6	0.2	1	1	1	0.0	1.7	0.2
1	1	1	0.0	0.2	0.2	1	2	1	0.0	0.9	0.2
4	2	1	50.6	10.3	1.3	4	1	1	39.9	6.9	1.1
5	1	1	25.1	2.4	0.2	4	1	1	17.4	1.3	0.2
5	1	1	7.1	0.2	0.2	4	1	1	3.2	0.0	0.2

Figure 8 Results of Scenario 1 (storage basins): total overflow volume in m^3 (left), water quality evaluation in a river stretch in the current situation (centre) and in Scenario 1 (right); water quality ranking goes from good to bad (1 to 5 and blue to red), which the figures in the right side of the matrixes are the yearly number of exceedances for the given duration and return period (see UPM).

Scenario 2 (Figure 9) shows that both the total overflow volume but especially the number of overflow events are reduced by the introduction of green roofs. An improvement for the affected river reaches is also noted for the evaluation with the UPM standards.

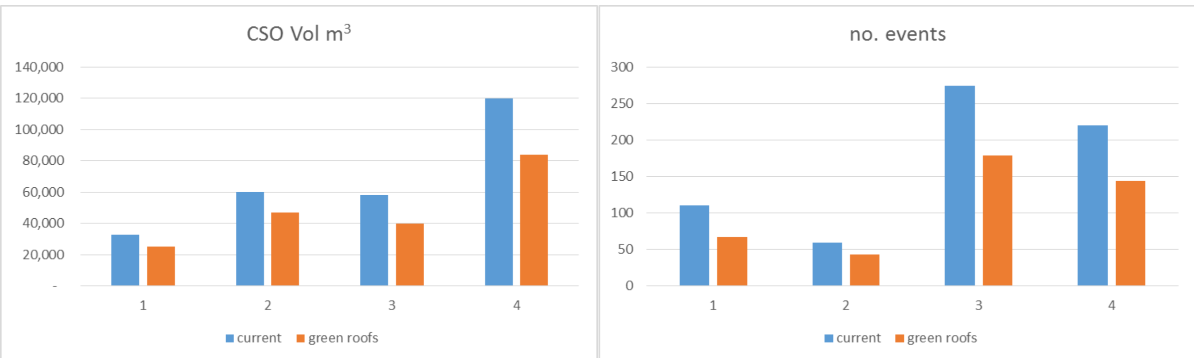

Figure 9 Results of Scenario 2 (green roofs): total overflow volume (left) and total number of events (right) in the four catchments.

Conclusions and ongoing investigations

The initial stage of this project is now ending and discussions are commencing with the Regulator to apply an Environment Quality Standard (EQS) approach to the permitting of CSOs in Odense. It is proposed that the UK UPM standards are used to demonstrate that rivers receiving intermittent wet weather discharges are compliant with Water Framework Directive water chemistry standards.

Meanwhile, a programme of further model calibration and validation will take place enabled by a comprehensive data collection programme using continuous water quality monitoring.

Aspects of uncertainty related to integrated modelling will be considered in the next project phases, as some of the authors are partners of the EU research project on Quantifying Uncertainty in Integrated Catchment Studies (QUICS)[3]. This will allow to improve the decision making process resulting from the use of the model.

The integrated modelling approach has demonstrated the importance of key dynamics within this system, notably the interaction of CSOs and river and sewer and WWTP. The disadvantages of a conventional approach to reducing every CSO spill through new storage are being understood and quantified.

VCS Demark will be applying the model to develop long-term strategies to deliver their 2030 objectives. The fast and stable simulation is already providing insight on the costs and benefits of different grey and green wet weather management strategies.

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[3] https://www.sheffield.ac.uk/quics

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