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Pollution from Urban Runoff

Oxygen Depletion in Streams and Rivers

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POLLUTION FROM URBAN RUNOFF
- oxygen depletion in streams and rivers

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INTRODUCTION

The main idea of this paper is to establish the following facts:

Biodegradable organic matter discharged from combined sewer overflows (CSO) gives rise to an acute effect on the dissolved oxygen (DO) concentration of a river. This acute effect consist of two subeffects: an immediate oxygen depletion which takes place in the polluted water volume passing down the river, and a delayed oxygen depletion which is associated with degradation of the organic matter accumulated at the river bottom during the passage of the polluted water volume.

Because of the fact that the acute effect is related to the loading of organic matter from a single event and not to the total loading from events over a specified period, statistical analysis of minimum DO concentrations for the single events in a rain series must be considered.

The impact on the DO concentration from CSO is considered the dominating pollutional effect on a river during a wet weather period. Management of CSO, e.g. designing basins in combined sewered urban catchments, must therefore be based on this effect.

A numerical computer model for DO stream simulation, taking relevant dry and wet weather processes into account, a water quality criterion for the river in question and a historical rain series are the main means to be used when managing CSO.

In the following the theoretical background for dealing with these facts in calculations will be given. Further litterature and information are given in the reference list of this paper.

BIODEGRADATION OF DISCHARGED ORGANIC MATTER IN A RIVER DURING A CSO EVENT

When dealing with soluble and particulate organic matter discharged from an overflow structure to a river it is important to notice the following two facts:

The organic matter can be removed from the water phase in the river with or without degradation of the substance.

Because of this difference in the removal mechanisms there are different types of effects exerted on the DO concentration in the river.

In the following these mechanisms and phenomena will be dealt with because they are important for the DO concentration during a CSO event.

Removal of organic matter from the water phase

Based on general knowledge of processes in rivers it appears reasonable to make a crude distinction between the following removal mechanisms for organic matter from the water phase:

Degradation in the water phase

Extraction to the sediments, i.e. absorption and adsorption processes

Sedimentation

Removal of organic matter by degradation in the water phase is due to pelagic (in the water phase) bacteria which consume organic matter and oxygen simultaneously. This is the phenomenon which is accounted for in the classical oxygen sag theory, which assumes a first order rate of removal.

Extraction of organic matter is a complex phenomenon that can be characterized simply as a fixation of organic matter at the bottom. "Bottom" in this sense means anything stationary in the river: the sediments, stones, plants and animals. There are several known versions of this mechanism. Sludge fungi absorb soluble organic matter directly from the water and exert an immediate oxygen demand on the water (Wuhrmann, 1974). Organic matter in the colloidal form can be adsorbed in biofilms by physical-chemical mechanisms and are subsequently degraded. Filter feeders catch particulate organic matter for their consumption.

Sedimentation is a well known process which can remove organic matter with a particle size above 50-100 μm.

All these phenomena lead to a decreased concentration near the bottom and accordingly a net transportation of organic matter to the bottom is generated.

Consequences for the oxygen demand in a river during a CSO event

The removal of organic matter in a river ultimately exerts an oxygen demand on the river water, but it does so in very different ways. Degradation in the water phase exerts itself as a simultaneous removal of oxygen from the water phase. At the other extreme, organics removed by sedimentation will be fixed to the bottom and be subject to a delayed degradation in the sediments. The

2

oxygen demand will not be exerted on the volume of water to which it was discharged from the overflow structure, but to the water that subsequently flows past the sediments. It is thus reasonable to make a crude distinction between those processes that exert an immediate oxygen demand and those processes that exert a delayed oxygen demand, Figure 1. As was already mentioned, the process extraction can give rise to both immediate and delayed oxygen demand. Absorption by organisms will lead to immediate oxygen demand, while adsorption will give rise to a delayed oxygen demand.
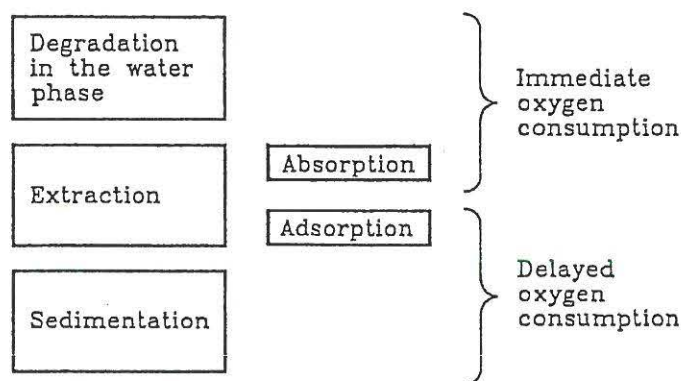

Figure 1:   *Terminology for processes that remove organic matter from the water phase and exert either an immediate or a delayed oxygen demand on the river water.*

The linkage between the removal mechanisms for organic matter and the DO consumption in the river can be summarised as follows:

An immediate oxygen demand is caused by degradation of the soluble organic matter in the water phase and by direct absorption of organic matter by benthic organisms, e.g. bacteria and fungi. In case of a CSO, these processes take place in the polluted water volume moving down the river.

In case of a delayed oxygen demand, the removal of the organic matter from the water phase takes place without consumption of oxygen. The organic matter becomes fixed to stationary objects, i.e. the sediments, stones, plants and organisms. In this fixed position the organic matter is degraded and a delayed oxygen demand is exerted on the water passing by. In case of a CSO this depletion will take place during as well as after the polluted water volume has passed by.

These facts are based on theoretical considerations and investigations in Danish rivers receiving CSO (Harremoës, 1982; Hvitved-Jacobsen, 1982 and Hvitved-Jacobsen and Harremoës, 1982). In these rivers the water velocity during dry weather and wet weather periods are of the same order of magnitude. In case of river systems where a CSO event gives rise to an increase in the water velocity, scouring and resuspension of the bottom sediments may add to the oxygen consumption (Kreutzberger et al., 1980).

3

Combined sewer overflow impact on the DO concentration of a river

The immediate and delayed oxygen consumption take place as a result of both continuous and intermittent discharges of organic matter to a river. During a steady state situation little attention is given to which part of the discharged organic matter is degraded with an immediate and which with a delayed DO consumption. However, during a CSO event it becomes very important: The delayed oxygen demand will not be exerted on the volume of water from which it was discharged but in the water that subsequently flows past the sediments. First order rates of adsorption and sedimentation in a river are in the order of 1.0-2.0 $m \cdot d^{-1}$ which can be compared with a rate of deoxygenation in the water phase of 0.2-0.6 d^{-1}. Therefore, it is not surprising that the delayed DO consumption in a river associated with degradation of raw wastewater, discharged from an overflow structure, may play an important role. Because the rates for organic matter removal by adsorption and sedimentation are relatively big, the critical DO deficit caused by these phenomena will be reached significantly upstream from the point where the critical DO concentration for the immediate oxygen consumption appears during passage of the polluted water volume.

Figure 2 illustrates this concept. The oxygen sag curve is shown during a CSO discharge and at different times, t, after the event, i.e. after the polluted water volume has passed the station in question. The time variation of the DO concentration at two stations downstream the point of discharge is also shown. In station 1 the immediate consumption is smaller than the maximum value of the delayed consumption which takes place at $t = 0$; for station 2 the opposite situation is the case. In order to illustrate the concept in a simple way, the delayed DO consumption is assumed to start when the polluted water volume has passed the station in question, althoug it in a real situation gradually increases during the period where the polluted plug passes by, because more and more organic matter is accumulated at the bottom during this period.

When calculating the effect of CSO loadings on rivers it is important to realise whether the immediate or the delayed DO consumption is the dominating process.

In small rivers where the "bottom" is dominating over the water phase the delayed oxygen demand is probably the most important. This is especially due to the following facts:

The particulate and colloidal part of wastewater discharged from overflow structures is dominating over the soluble fraction.

The removal rate to the bottom in a river for particulate and colloidal organic matter is bigger than the deoxygenation rate for soluble organic matter in the water phase.

The critical point for the delayed oxygen demand is therefore relatively close to the point of discharge compared with the critical point for the immediate oxygen demand. Lateral inflow to the river and tributarys will therefore result in a less important diluting effect.

The rate of degradation of the freshly adsorbed and settled organic matter at the bottom is relatively high.

The duration of the delayed oxygen demand is typically 0.5-1.0 day and therefore normally longer than the duration of the runoff period which is related to the time of travel of the polluted water volume in the river.
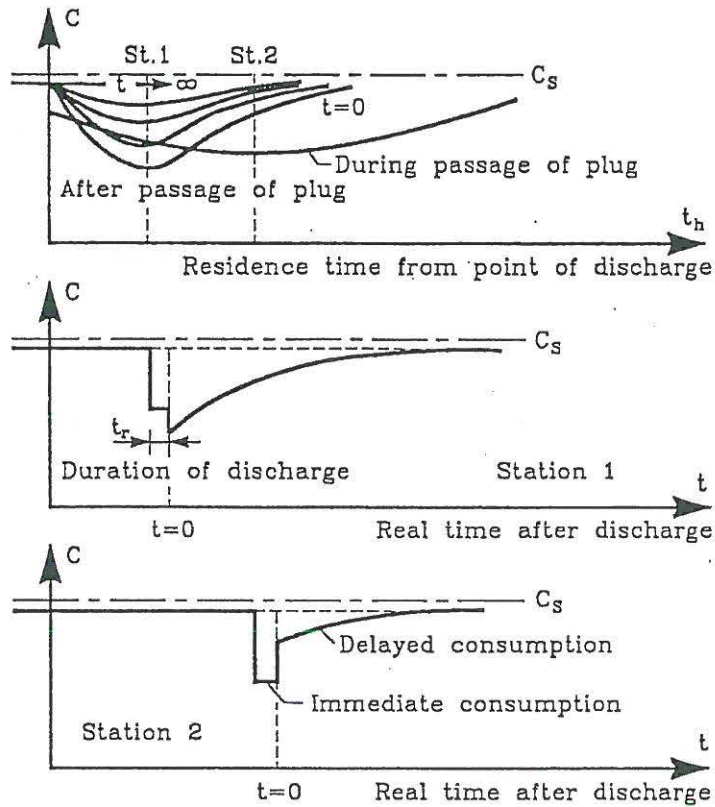
Figure 2: *Illustration of the oxygen sag curve during and after a CSO event of short duration. The immediate and delayed oxygen consumption give rise to very different observations; see text. It should be noticed that t_h is the time of travel for a water volume from point of discharge; this parameter is therefore equivalent to the distance downstream this point.*

THE WATER QUALITY CRITERION

The definition of a water quality criterion can be given as follows:

A water quality criterion represents ideally a concentration of a substance or a level which results in a certain degree of environmental effect upon which scientific judgement may be based. For practical purposes a criterion means a designated concentration of a substance that, when not exceeded, will protect an organism, an organism community or a prescribed water use or quality with an adequate degree of safety.

This definition of a water quality criterion makes the following a basic and important statement: the effects which are seen in a receiving water system for a given pollutant and pollutant concentration must be in accordance with the details of the corresponding water quality criterion.

In Denmark the presence of specified fish populations in the rivers are the main concern. Examples of pollutants which can affect the activity or the survival of the fish are:

5

Pollutants which result in acute effects:

Biodegradable organic matter resulting in low DO concentrations.
Hydrogen sulfide.
Undissociated ammonia.

Pollutants which result in accumulative effects:

Heavy metals.

As an example the Danish water quality criterion for DO in a trout river is a daily median and minimum DO value of 9 mg·l^{-1} and 6 mg·l^{-1}, respectively.

These values must be observed for the continuous discharges, e.g. wastewater treatment plants. However, it should be quite clear that as far as CSO is concerned these values will be violated for extreme events. Therefore, if CSO to a river should ever be accepted, a different approach for the water quality criterion must be formulated.

First it should be mentioned that the DO concentration in the river affected by discharge of biodegradable organic matter from CSO is the fundamental parameter to be observed and for which a water quality criterion must be specified. As already indicated other pollutants may be of concern too, but normally they are less important and if the loading of organic matter to the river is reduced they typically follow the same trend.

A fish-kill caused by DO depletion due to CSO will have exterminated the fish population for as long a time as it takes to build up a new population or to reestablish it by migration. The concern is: how infrequently does the event occur, or how frequently can it be allowed? This is judged by extreme event statistics, and not through the above given quality criterion related to continuous discharges.

Figure 3 shows the concept of the water quality criterion related to CSO. The criterion selected is that half the fish population may be killed at the DO concentration and duration indicated for the rarest events (from 8 to 16 year return period). The criterion is given for two durations of exposure time, 1 and 12 hours, for the fish population.
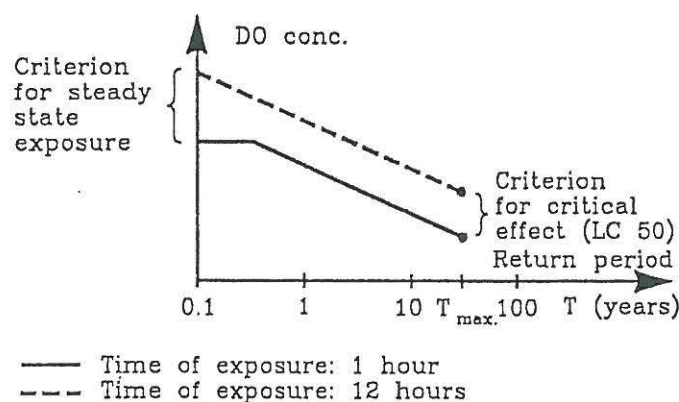

Figure 3: The principle of a water quality criterion for dissolved oxygen as to the impact of CSO on a fish population in a river.
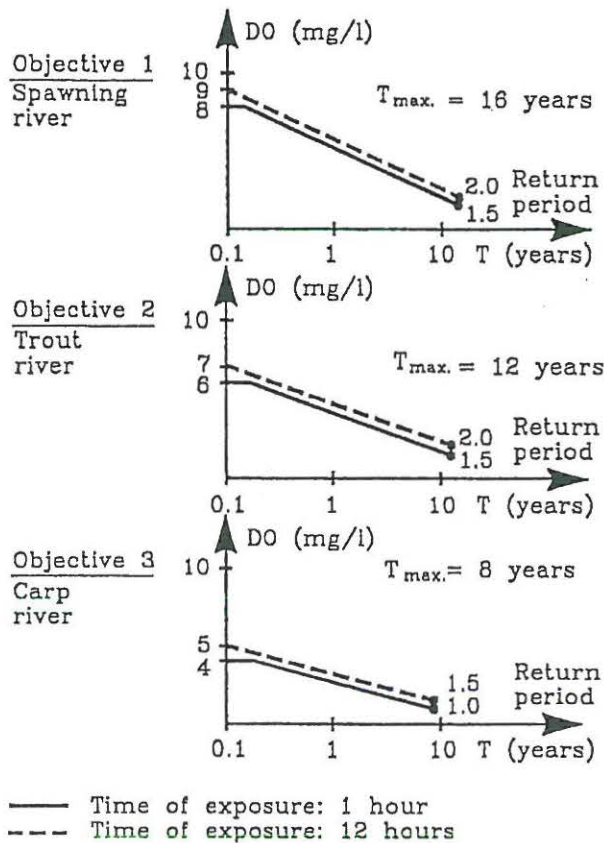
6

Figure 4: Recommended water quality criteria for extreme event statistics on required DO concentrations in rivers as affected by CSO.

Figure 4 shows the criterion recommended by the Danish Water Pollution Control Committee. Three levels of water quality are given corresponding to habitats for spawning trout fish, trout fish and carp fish. Similar curves - but with much less quality requirements - exist for rivers with no demands for presence of fish populations.

Finally, it should be mentioned that actually calculated minimum DO concentrations based on a historical rain series should be compared with the relevant quality criterion. Examples will be given in the section "Case Study Based on the DOSMO 3.0 Model", page 13.

MODELLING THE CSO IMPACT ON THE DO CONCENTRATION OF A RIVER

Theoretical background

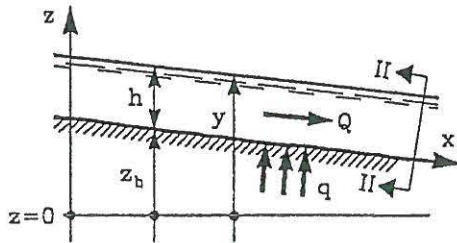In this section the theoretical background for the DO-models will be discussed.

Open channel flow

The basic equations of unsteady flow in open channels (including streams) are the well-known Saint Venant equations:
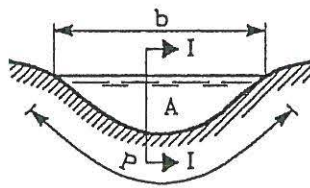
$$\text{continuity equation:} \quad \frac{\partial Q}{\partial x} + b \cdot \frac{\partial y}{\partial t} = q \tag{1}$$

$$\text{momentum equation:} \quad \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g \cdot A \cdot \frac{\partial y}{\partial x} = - g \cdot A \cdot S_f \tag{2}$$

Longitudinal section I–I

Cross Section II–II

where - referring to Figure 5:

Q = flow (m³·s⁻¹),
y = z_b+h = water level (m),
z_b = vertical bottom coordinate (m),
h = water depth (m),
b = channel width at the water surface (m),
q = lateral inflow (m³·s⁻¹·m⁻¹),
A = cross section area (m²),
g = the gravitational acceleration (m²·s⁻¹),
S_f = friction slope = $(Q \cdot |Q|)/(M^2 \cdot R^{4/3} \cdot A^2)$,
M = Manning number (m¹ᐟ³·s⁻¹),
R = A/P = hydraulic radius (m),
P = wetted perimeter (m),
x = space-coordinate (m),
t = time (s).

Figure 5: *Definition sketch, open channel flow.*

These equations are based on the following conditions:

- unsteady flow in open channels is one-dimensional
- the pressure distribution is hydrostatic (shallow water condition)
- the water is homogeneous and incompressible
- the average bed slope is small
- the friction can be determined as for steady flow (e.g. by the Manning formula)
- lateral inflows take place in right angles to the stream.

Transport of materials in open channel flow

The theoretical basis for mathematical modelling of one-dimensional transport of materials by unsteady flow in streams was developed by Taylor (1954).
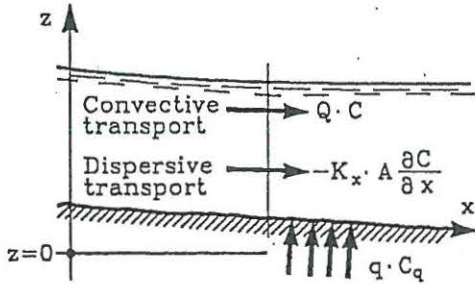
The transport of materials is divided into 2 transport-processes:

- convective transport by the mean flow, and
- dispersion due to turbulent diffusion

Taylor showed that in the case of fully developed pipe flow, the longitudinal dispersion of a tracer which is fully mixed over the cross section vill behave as a Fickian diffusion process at large distances from the point of injection.

8

With this concept the law of conservation of mass is:

$$\frac{\partial(A \cdot C)}{\partial t} + \frac{\partial(Q \cdot C)}{\partial x} = \frac{\partial}{\partial x}\left(K_x \cdot A \cdot \frac{\partial C}{\partial x}\right) + q \cdot C_q - s \qquad (3)$$

where - referring to Figure 6:

C = average concentration of material over the cross section ($g \cdot m^{-3}$),

K_x = longitudinal dispersion coefficient ($m^2 \cdot s^{-1}$),

C_q = concentration of material in lateral inflow ($g \cdot m^{-3}$),

s = sink term per unit length ($g \cdot s^{-1} \cdot m^{-1}$).

Figure 6:   Definition sketch,
transport of material by unsteady flow.

Eq. 3 is normally known as the transport-dispersion equation.

The sink term, s, specifies removal and/or production of material caused by physical, biological, or chemical processes.

DO depletion in streams

Investigations have shown that discharge of biodegradable organic matter to a stream during a CSO event results in an immediate and a delayed DO depletion (Hvitved-Jacobsen, 1982 and Hvitved-Jacobsen and Harremoës, 1982). This implies that calculations by Eq. 3 of DO-concentrations in streams during and after a CSO event, presuppose that concentrations of both soluble and particulate organics have been calculated from the same equation.

As already mentioned soluble organics are exposed to degradation in the water phase. Therefore, when Eq. 3 is applied to this fraction of organics

$$C = L_S = COD_{SOL}$$

and a 1' order approach is used for the sink term:

$$s = K_1 \cdot L_S \cdot A \qquad (4)$$

where
K_1 = 1' order degradation constant in the water phase (s^{-1}),

L_S = concentration of soluble organic matter in the stream water resulting in an immediate oxygen depletion ($g \cdot m^{-3}$),

COD = chemical oxygen demand ($g \cdot m^{-3}$).

9

The particulate fraction of organics is removed from the water phase by physical or chemical adsorption to the stream bottom or by sedimentation.
When Eq. 3 is applied to this fraction of organics

$$C = L_P = COD_{PART} = COD_{TOTAL} - COD_{SOL}$$

and the following 1' order approach for the sink term is used:

$$s = k \cdot \frac{L_P}{h} \cdot A$$

where $\quad k$ = 1' order rate of adsorption or sedimentation $(m \cdot s^{-1})$,
$\quad L_P$ = concentration of particulate organic matter in the stream water resulting in a delayed oxygen depletion $(g \cdot m^{-3})$.

This results in the following mass balance equation for the amount of particulate organic matter at the stream bottom when biodegradation of this fraction is modelled by 1' order kinetics:

$$\frac{dL_B}{dt} = k \cdot L_P - K_4 \cdot L_B$$

where $\quad K_4$ = 1' order degradation constant at the bottom (s^{-1}),
$\quad L_B$ = amount of adsorbed or settled particulate organic matter - related to an overflow event - per unit area of bottom $(g \cdot m^{-2})$.

The oxygen depletion due to L_B is given by

$$s = K_4 \cdot \frac{L_B}{h} \cdot A \tag{5}$$

When Eq. 3 is applied to DO the following processes are taken into account: Re-aeration, photosynthesis and total respiration added to the CSO-related DO depletion terms Eq. 4 and 5. The combined DO sink term is as follows:

$$s = \left[K_2 \cdot (C_S - C) + P - R - K_1 \cdot L_S - K_4 \cdot \frac{L_B}{h} \right] \cdot A \tag{6}$$

10

where C = DO concentration ($g \cdot m^{-3}$),
           K_2 = reaeration constant (s^{-1}),
           C_s = saturation concentration ($g \cdot m^{-3}$),
           P = $P(t)$ = DO-production rate of aquatic plants ($g \cdot m^{-3} \cdot s^{-1}$),
           R = $R(t)$ = total consumption rate during dry weather conditions due to organic matter degradation in the water phase and at the bottom, nitrification and plant respiration ($g \cdot m^{-3} \cdot s^{-1}$).

DISSOLVED OXYGEN STREAM MODELS

This section deals with the following three DO-models: DOSMOSIM, DOSMO and DOSMO 3.0.

A simplified DO stream model (DOSMOSIM)

On condition that the flow is steady and uniform, and transport by dispersion is neglected, i.e. dry weather conditions, Eq. 3 and 6 result in:

$$\frac{dC}{dt} = K_2 \cdot (C_S - C) + P - R \qquad for \quad \frac{dx}{dt} = U \qquad (7)$$

where U = cross sectional average stream velocity ($m \cdot s^{-1}$).

Basically, Eq. 7 is an extension of the classical Streeter-Phelps model (Streeter et al., 1925). A simple solution to Eq. 7 based on (Simonsen and Harremoës, 1978) is:

$$C = C_m + \Delta C \cdot \frac{\beta}{2 \cdot \beta'} \qquad (8)$$

where C_m = mean concentration in the stream during dry weather conditions ($g \cdot m^{-3}$),
           ΔC = total DO fluctuation in the stream during dry weather conditions ($g \cdot m^{-3}$),
           β = a model expression for the daily relative DO fluctuation (see Simonsen and Harremoës, 1978),
           β' = $|\beta|_{min}$ for $\beta < 0$ and β_{max} for $\beta > 0$.

During wet weather conditions, Eq. 7, extended with the immediate and the delayed DO depletion, is still considered valid:

$$\frac{dC}{dt} = K_2 \cdot (C_S - C) + P - R - K_1 \cdot L_S - K_4 \cdot \frac{L_B}{h} \qquad (9)$$

11

The above mentioned investigations have indicated that $K_1 \ll (K_4/h)$ for (Danish) rivers. Therefore, when immediate DO depletion in Eq. 9 is neglected, we have the following analytical solution:

$$C(x,t) \;=\; C_m \;+\; \Delta C \cdot \frac{\beta}{2 \cdot \beta'} \qquad\qquad for \quad t \le [(x-x_0)/U] + t_a \qquad (10a)$$

$$C(x,t) \;=\; C_m \;+\; \Delta C \cdot \frac{\beta}{2 \cdot \beta'} \;-\; \qquad\qquad for \quad t > [(x-x_0)/U] + t_a \qquad (10b)$$

$$L_0'(t) \cdot \left(\frac{K_2}{K'}-1\right)^{-1} \cdot \left[\exp\!\left(K' \cdot \frac{x-x_0}{U}\right) \;-\; \exp\!\left(K_2 \cdot \frac{x-x_0}{U}\right)\right]$$

where

x_0 = station, where overflows takes place (m),
t_a = duration of CSO event (s),
K' = (k/h), (s^{-1}),
$L_0'(t)$ = $K_4 \cdot (P_P/(Q_0+Q_B)) \cdot exp(-K_4 t)$,
P_P = total quantity of particulate organic matter discharged during a CSO event (g),
Q_0 = mean flow value of the SCO event (m$^3 \cdot$s^{-1}),
Q_B = constant baseflow in the stream (m$^3 \cdot$s^{-1}).

DOSMO

In the DOSMO model unsteady flow and transport by dispersion are taken into account. This model consists of two integrated models, a one-dimensional hydrodynamic (HD) model based on Eq. 1 and 2, and a one-dimensional transport-dispersion (TD) model based on Eq. 3.

The HD-model calculates the variations in space and time of the flow and water depths after which the TD-model calculates the variations in space and time of soluble organic matter, particulate organic matter and finally the DO concentration. In these calculations the different sink terms in Eq. 3 are modelled according to Eq. 4 - 6. This implies that a model, which calculates the variations in space and time of the amount of particulate organic matter adsorbed and/or settled to the bottom of a stream is a part of the entire model. The method of solution is in all cases the numerical method of finite differences.

The HD-model is based on the Verwey variant of the implicit Preismann scheme (Cunge et al., 1980) while the TD-model in DOSMO is based on the implicit Stone & Brian scheme (Fisher et al., 1979). Both schemes are unconditionally stable and free of numerical dispersion.

The DOSMO 3.0 stream model

The use of DOSMOSIM for extreme events statistics is rapid on a personal computer, but is restricted due to the conditions mentioned above. Contrary DOSMO is well fitted, but compared to DOSMOSIM the time of computation with this complex numerical model will increase with a factor of approximately 1000 per CSO event. Therefore, a more rapid model - covering the major part of the qualities of DOSMO - was developed. This new model, DOSMO 3.0, has decreased the time of computation per CSO event with a factor of approximately 100 compared to DOSMO.

In DOSMO 3.0 the unsteady stream flow is calculated according to the concept of an undamped kinematic wave, that is by simply routing the flow profile downstream and calculating the corresponding water depths by the Manning formula. When dealing with soluble and particulate organics as well as DO stream concentrations, DOSMO 3.0 neglects the transport by dispersion and, consequently, the calculations are performed by the method of characteristics.

DOSMO 3.0 is now available as an add-on model to MOUSE, the Danish model system for urban sewers (Lindberg and Joergensen, 1986). This means that for a historical rain series, MOUSE can be used for computing discharged quantities of organic matter to a stream through the overflow structures in an urban sewer. For these CSO's, DOSMO 3.0 calculates the 1 hour minima of DO stream concentrations, which form the basis of a statistical analysis of extreme events. This extreme event statistics can be compared to a water quality criterion for the river in question.

CASE STUDY BASED ON THE DOSMO 3.0 MODEL

A case study based on the DOSMO 3.0 model has been performed based on data from the Klausholm stream in the Northern part of Jutland, Denmark.

From a small town, Hjallerup, with 3,000 inhabitants and a total reduced catchment area of 42.2 ha, CSO is discharged to the stream, which have a dry weather flow variation from 0.3 to 0.55 $m^3 \cdot s^{-1}$ and a width varying between 3 and 5 m.

It is important to discuss if rain events in case of a recorded rainfall series should be treated as single or coupled events with respect to DO depletion in streams. This problem is related to whether the initial conditions in a DO-model should correspond to wet weather conditions or not, i.e. if there is degradable organics left in the stream from a previous CSO event or not. In order to clarify this problem a coupling procedure was implemented in DOSMO 3.0.

For a 33 year Danish rainfall record containing 1571 rainfall events the amount of degradable organics discharged to the stream was calculated by the SAMBA model of the MOUSE program system. Based on these computations DOSMO 3.0 calculates the 1 hour minimum DO concentration in the stream for the CSO events, partly considered as coupled events, partly considered as single events. The coupling procedure implies that 632 of the 1571 CSO events should be considered as coupled events. These 632 coupled events appear in 279 combined events. For each of these combined events the 1 hour minimum DO value was compared with the 1 hour minimum DO value for the same CSO obtained when all 1571 CSO events were considered as non-coupled, single events, Figure 7. From this figure it is obvious that the coupling procedure is an essentiel part of a DO-model.

Furthermore, it is important to decide if extreme event statistics should be carried out based on the minimum DO value for the 279 combined events or if each of the 632 coupled events must be taken into account. The decision must be taken based on the character of the receiving stream effect. Analysis of the results of DOSMO 3.0 showed that the coupled events within a combined event typically result in minimum DO-value at different locations in a stream. Therefore, the extreme event statistics must include each of the 632 coupled events and of course all (1571 - 632) = 939 single events, Figure 8.
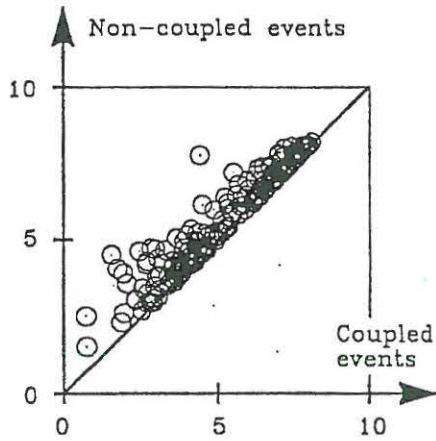
13

Figure 7:   1 hour minimum DO stream
             concentration $(g \cdot m^3)$.
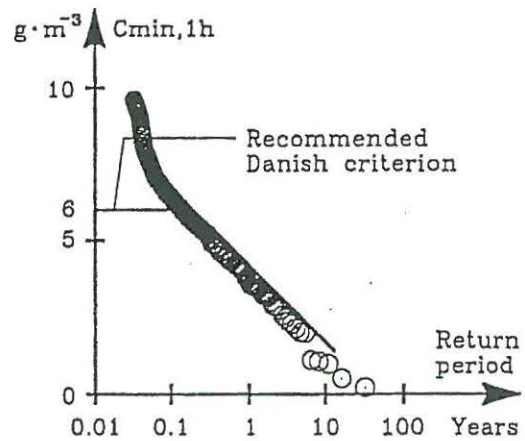

Figure 8:   Extreme events statistics
             compared to recommended
             Danish water quality cri-
             terion.

The criterion shown in Figure 8 refers to trout fish water (see Fig. 4). Fig. 8 illustrates that some changes could be implemented in the sewer system of Hjallerup in order to observe the criterion.

Another question is: To what extent does the annual variations of a CSO event influence the extreme event statistics. In order to answer this question the 300 highest ranked CSO events were considered, Figure 9. These events cover return periods between approximately 0.1 and 33 years.

This figure indicates that only rain events in the period May - September need to be taken into account in case of extreme events statistics. This is not surprising at all, because this period of the year is characterized by having the lowest values of C_m and the largest values of ΔC due to temperature conditions and biological activities, similarly, the rate of degradation of organic matter is high.
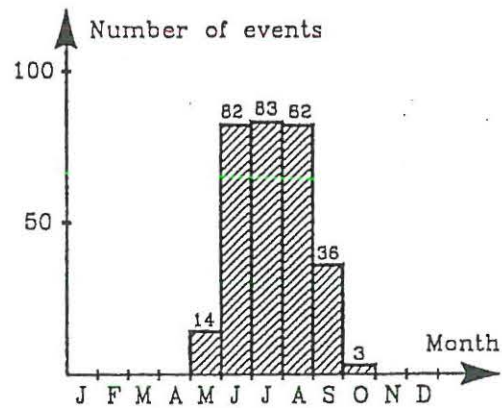

Figure 9:   Time of year of 300 highest
             ranked (with respect to 1
             hour minimum DO concen-
             tration) CSO events in a 33
             year Danish rainfall record.

14

CONCLUSIONS

The means for calculating the impact of combined sewer overflows on the dissolved oxygen concentration of a river is available. The results of such computations have to be evaluated in the context of extreme statistics for the effect of single overflow events in a rain series and a water quality criterion for the river in question.

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