Nordic Hydrology, 8, 1977, 237-248

Management of Urban Runoff and Wastewater in the Oslofjord Area

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To alleviate the pollution in the Oslofjord region it is planned to transport wastewater to a central treatment plant by a 35 km tunnel system. The objective of the study was to analyze the consequences of a reduced treatment plant capacity vs. the utilization of the tunnel as a retention basin. The analysis was performed by the use of a recently developed mathematical model for urban runoff and drainage. Simulations were performed for large rain events and for all rains during a summer season. The most important result of the study was that the treatment plant could be reduced to half its original capacity if the tunnel was utilized as a retention basin without any increase, in fact a decrease, in the total pollution load on the fjord.

Introduction

The inner Oslofjord receives wastewater from a population of about 700,000 persons. The fjord has a tremendous recreational value for the people in the Oslo area. When the water in the 50's and 60's seemed to deteriorate, this caused considerable concern. A large investigation of the Oslofjord was initiated in the early 60's. The investigation (Norsk institutt for vannforskning 1967) revealed that the main reason for the deterioration of the water quality was algal growth in the surface layers of the fjord. Phosphorus supplies from domestic wastewaters were pointed out as a major reason for the increased algal growth. A subsequent technical evaluation (Norsk institutt for vannforskning 1970) of alternative solutions for the collection and treatment of the wastewater recommended that wastewater from the western part of Oslo and from the local communities west of the Oslofjord be collected and transported in a tunnel to the outer part of the inner Oslofjord. The recommendation also included chemical treatment of the wastewater to remove phosphorus and disposal of the treated wastewater in the deep layers of the fjord.

The local communities involved (Oslo, Bærum, Asker and Røyken) decided to cooperate in accordance with the recommendations, and in 1974 the plans for a 35 km tunnel and a central treatment plant were presented.

The plans assumed a design dry weather flow of 4.1 m^3/s in the year 2000. For all areas with combined sewers a storm overflow setting of 4 DWF at each inlet to the tunnel was assumed. This would give a maximum wet weather flow of 9.6 m^3/s to the treatment plant.

A treatment plant with 9.6 m^3/s capacity would require heavy investments, and thus it was desirable to reduce the capacity, for instance to the half in the initial building step in order to postpone investments. The consequences of a reduced capacity of the treatment plant was, however, unknown, and at the same time there was a rising concern about storm water pollution. There was an obvious possibility to use the 35 km tunnel as a retention basin. A special task group was appointed to evaluate this possibility. This paper gives a summary of the work and findings of the group.

Approach

To evaluate the consequences of a reduced treatment plant capacity vs. the utilization of the transport system as a retention volume for an area inhabited by 700,000 people is extremely complicated. It was believed that the only possible way was to apply a systems analysis approach using mathematical modelling.

The possibilities for applying such a solution were favourable as a mathematical model for urban runoff and drainage recently has been developed at the Norwegian Institute for Water Research (NIVA) (Lindholm 1971).

In the design of sewer systems, interest is mostly concentrated on extreme flows with potential flooding damage. When the pollution of the Oslofjord area due to combined sewer overflows has to be evaluated, extreme situations that may occur every 5th or 10th year, are of minor interest. It was felt that the largest rains that occur regularly during each summer, would be of interest to evaluate. Because of the limited rate of water exchange in the fjord, it was also of interest to evaluate the total load on the fjord during a whole year or during an entire summer season. To actually simulate a whole year's recorded rainfall minute for minute would give very high computer costs. As rain data for the catchment area for some time have been collected on magnetic tape, it was possible to develop a computer programme that could transform a large number of rains into a moderate number of »base rainfalls«, and calculate the frequency of each base rainfall and its average rain intensity and duration. The computer programme is described in detail by Lindholm (1976).

The Mathematical Model

The mathematical model at the Norwegian Institute for Water Research has been developed since 1971 and includes surface runoff and the routing of flow and pollutants through sewers, storm overflows, pumping stations and retention basins.

The routing of the hydrographs through the network is in accordance with a storage routing technique similar to that used by the modified RRL-method (Watkins 1962). This is an approxmative method, but for sanitary engineering purposes it has proved to be adequate (Sjøberg 1974).

The pollutograph from each subcatchment is added to the pollutograph in the network upstream of this node. The pollutographs are routed through the sewer lines in accordance with the »plug flow« concept. However, in the retention basins and in the pumping sumps the pollutographs are routed through in accordance with the »complete mixing« concept. All constituents are regarded as conservative when they pass through the network.

To use the NIVA-model the necessary input data are: Sewer network data, rain data, runoff coefficients, sewer system retention basin volumes, flow and concentration of wastewater at dry weather flow, and concentration of pollutants in storm-water and combined sewer overflows. Extensive research had recently been undertaken in the Oslo area on quantity (Hetager 1975) and quality (Lindholm et al. 1976) of urban runoff, - input data of the largest importance, but seldom available as anything else but qualified guesses. It was thus believed that it was possible to do a realistic systems analysis.

Input Data

Sewer Network

The local sewer network is immense and consists mostly of combined sewers. Although it was simplified to a considerable degree, it still represented some 300 nodes in the analysis. For all stretches data on diameter and inclination of the pipes were collected. All major overflows and pumping stations in the local sewer system were included in the study as well as the overflows at each of the 28 inlet points to the tunnel. Due to the simplification the calculated data are of a limited value in an evaluation of the local sewer system. It is, however, believed that the data input of the sewer network is sufficiently accurate for the large scale analysis that was the prime objective of the study.

The total length of the tunnel is about 35 km. Fig. 1 shows, highly simplified, the tunnel and the approximate location of the retention basins.

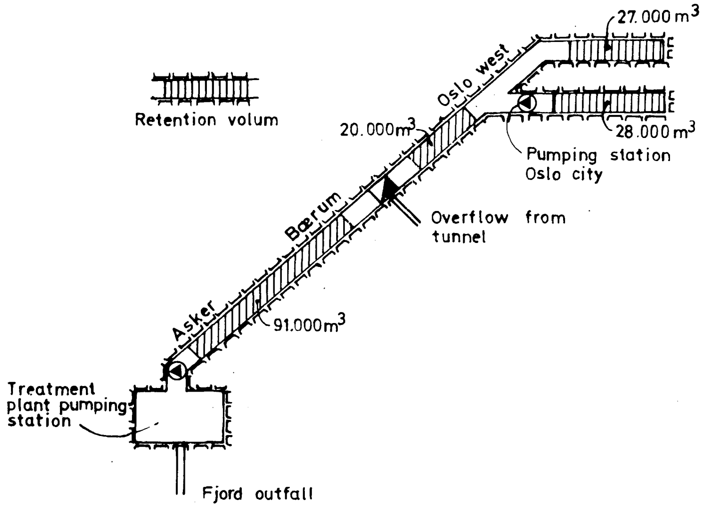

Fig. 1. Tunnel with retention basins.

Dry Weather Flow

Data on dry weather flow in the different districts of the total catchment area is compiled in Table 1.

All analyses on pollution transport are based on phosphorus. Each person is assumed to produce 2.5 g P/day and an industrial waste population equivalent based on flow is assumed to produce 1.0 g P/day.

Rain Data

To simulate large rains, rain data in the Oslo area for the last 5 years were examined. The 26 mm rain of July 16 and the 19.8 mm rain of Sept 5, 1974 were judged to be typical rains that will each occur either once or twice a year. Rain data from three rain gauges in the area were examined. It was revealed that for all large rains there were considerable differences in rain intensities at the same time. As the large drainage area in this project could not be handled in one run by the computer, it was split into three

Table 1 - Population and wastewater generation

District	Population and industry waste population equivalents[1]	Wastewater production l/cap.day	Total mean dry weather flow in district m^3/s	Area served by combined sewers ha
Oslo City	311,141	414	1.49	1468
Oslo West	117,393	414	0.85	3651
Bærum	108,171	623	0.78	2979
Asker	43,000	623	0.31	0
Total	639,705	463[2]	3.43	8098

1) Industrial wastewater population equivalents were based on flow.
2) Weighed mean.

parts. This splitting made it possible to use different rainfall patterns on each of the three areas.

In order to get base rainfalls for simulation of total pollution load during longer time periods, the data from the Øvrevoll rain gauge in Bærum, were processed. The base rainfalls are compiled in Table 2.
Rainfalls with lower intensity than 2 l/s. ha are not taken into consideration, because the runoff from the bulk of these rains is neglible.

Table 2 - Base rainfalls representing 6 summermonths

Rain-duration	*Rain intensity l/s ha* 2-7	7.1-15	>15	
	9	2	5	Number of rainfalls
	37	32	18	Mean duration (min.)
1-60	4.4	12.4	23.9	Mean intensity (l/s ha)
min.	1.0	2.4	2.6	Precipitation (mm per event)
	10	3	1	Number
	111	118	85	Mean duration (min.)
60-180	4.2	9.8	21.6	Mean intensity (l/s ha)
min.	2.8	6.9	11.0	Precipitation (mm per event)
	24	3	0	Number
greater	437	343	-	Mean duration (min.)
than	3.4	9.8	-	Mean intensity (l/s ha)
180 min.	8.9	20.2	-	Precipitation (mm per event)

Runoff Coefficient

The runoff coefficient is probably the factor attended with the greatest uncertainty in the calculations of the storm flow. Preliminary data from an ongoing project (Hetager 1975) were evaluated to find the runoff volume coefficient. For Oslo City it has been estimated to be 0.5 and for the remaining districts from 0.3 to 0.15, depending on the population density and the percentage of impervious area.

Pollution in Storm Runoff

To calculate the pollution in storm water, data from an ongoing research project (Lindholm et al. 1976) have been used. Preliminary examination of data revealed that the concentration of phosphorus roughly was constant and the mass transport thereby a linear function of the water flow. The concentration of phosphorus in storm water, including pipe deposit wash out, was estimated to 5.3 mg P/l for Oslo City, 2.9 mg P/l for Oslo West and 2.4 mg P/l in the Bærum district.

Simulation Results

Large Rain Events

Hydrograms and pollutograms have been calculated for the one time and two times per year rain events for the four following alternatives:

a) All storm water and wastewater entering the sewer network is discharged to the tunnel. There are no local overflows and no utilization of retention volumes.
b) Same condition as in a), but the storm overflows in the local sewer network are in operation.
c) Same condition as in b), but the tunnel is utilized as a retention basin, volume 75,000 m^3.
d) As c), but with 166,000 m^3 volume.

Alternative a) is hypothetical as local overflows are unavoidable at the present time, but is of interest as it gives the maximum possible flow to the tunnel.

In alternatives b, c, and d the setting of the local storm overflows in the calculations is in accordance with what is believed to be the best practicably achievable for the next decades.

In alternatives c and d, there is a controlled outlet from the three upper retention basins. Preliminary simulations indicated that an outlet of 0.7 m^3/s, 3 m^3/s and 4.5 m^3/s respectively from the 27,000 m^3, 28,000 m^3 and the 20,000 m^3 volume was approximately optimal.

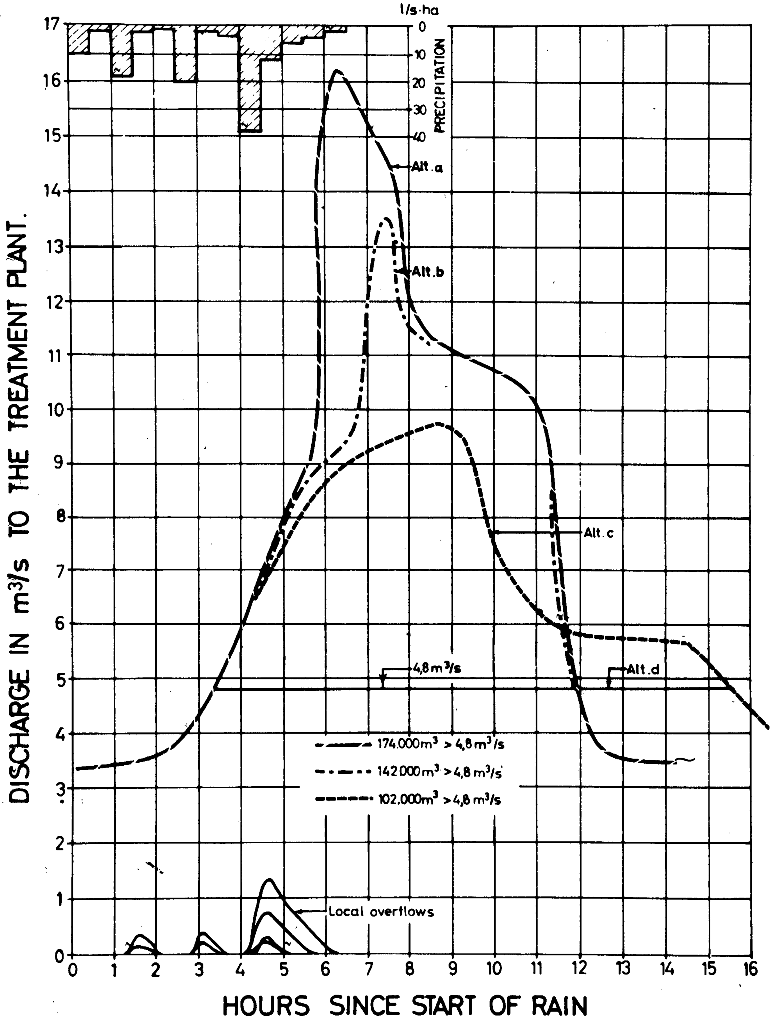

Fig. 2. Simulated hydrographs at the treatment plant inlet during the Sept 5, 1974 rain event.

Fig. 2 shows the calculated hydrographs at the treatment plant inlet on September 5, 1974 (two times per year event).

Assuming a treatment plant capacity of 4.8 m^3/s, the volume discharged at overflows and the utilized retention volumes are found in Table 3 for this rain and the 1 year rain.

The pollutographs at the inlet to the treatment plant were also calculated and are reported in detail elsewhere (Lindholm, Saltveit and Glomnes 1975). As could be expected, the transport of phosphorus to the treatment plant during large rains is

Table 3 - Volume discharged at overflows and utilized retention volumes

	Discharged volume at overflows in m³ From the tunnel		From local network		Fraction of basins utilized in %	
	½ year rain	1 year rain	½ year rain	1 year rain	½ year rain	1 year rain
Alt. a	173300	206800	0	0	0	0
Alt. b	142000	183000	32300	23800	0	0
Alt. c	102000	157000	32300	23800	70	62.9
Alt. d.	11000	66000	32300	23800	86.4	83.2

several times the dry weather transport. To illustrate the pollution load on a 24 hour basis, the mass balance for the half-year rain event is given in Fig. 3 (alt. d) and Fig. 4 (alt. b). A treatment plant capacity of 4.8 m^3/s is assumed.

During the day 2214 kg of phosphorus are generated in the catchment area, of which 1154 kg are due to the rain. The 75 kg P diverted at storm overflows in the local network are unavoidable, but there is a remarkable difference in the amount of phosphorus diverted from storm overflows in the tunnel, 251 kg P with retention and 695 kg

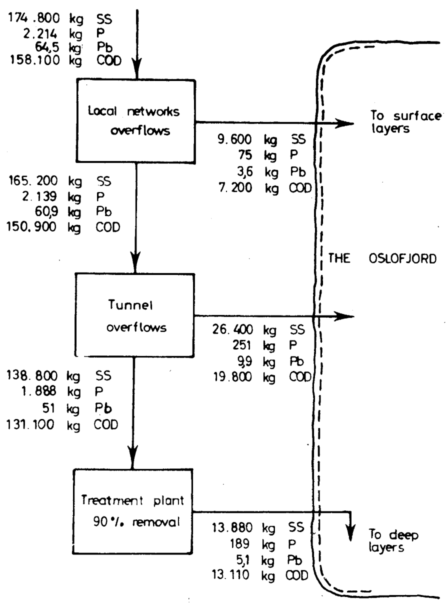

Fig. 3. Mass balance for the Sept 5, 1974 rain event. Retention basin in the tunnel.

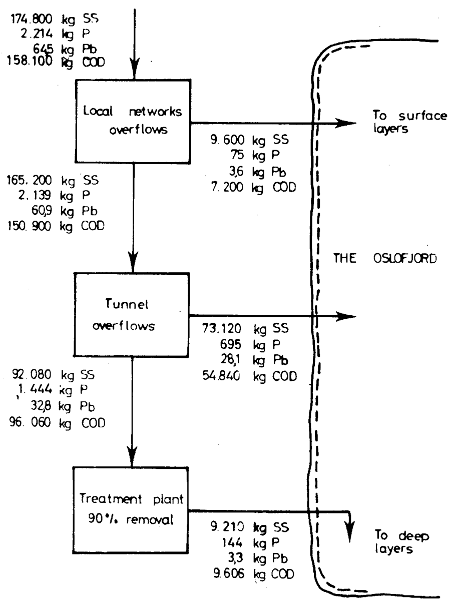

Fig. 4. Mass balance for the Sept 5, 1974 rain event. No Retention basin in the tunnel.

P with no retention. When comparing with the effluent discharge of 189 kg it has to be remembered that this is disposed of into the deep layers of the fjord, but the overflows in most cases enter the surface layers.

Simulation of Runoff During the Summer Season

In order to simulate the amount of discharges and the total pollution load in the six summermonths, the base rainfall method was used. In Fig. 5 the volume of untreated wastewater and storm runoff that divert at the local overflows and tunnel overflows is shown vs. the capacity of the treatment plant. The two lower curves represent alternative d with 2.9 and 3.4 m^3/s DWF. The conditions for the upper curve are the same (3.4 m^3/s), but with the exception that there are fixed overflow settings of 4 DWF at the tunnel inlets.

It may be noticed that 140.000 m^3 are discharged in the local network overflows when there is no overflow on the tunnel inlets, and 540,000 m^3 when there is an overflow at the tunnel inlets. These amounts are independent of the treatment plant capacity. The difference between the curve and the amount from local overflows is overflows from the tunnel.

As the curves indicate, it is very unfavourable to have a storm overflow on the tunnel inlets, that was the intention in the preliminary plans. The preliminary plans also recommended that the treatment plant should have a capacity of 9.6 m^3/s. These simulations show, however, that when the tunnel is utilized as a retention volume, a capacity beyond 5.6 m^3/s will give no further benefit.

In Fig. 6 is shown the amount of phosphorus which discharges via the local and tunnel overflows during the summerseason. If, for instance, the treatment plant has a capacity of 4.8 m^3/s, 1,000 kg P will discharge at overflows to the fjord during the summer. The simulations also show that a rather small decrease in the DWF will give a substantial decrease of the pollution diverted from overflows. Hence ground water infiltration abatement programmes and elimination of excessive water can be useful ways to prevent pollution from storm overflows.

A mass balance for the whole summer of suspended solids, COD, P and Pb is shown in Figs. 7 and 8 for alternatives d and b respectively.

It may be noticed that 205 tons P are generated in the catchment during the summer from storm runoff and ordinary wastewater. Of this 0.5 ton P discharges at the local network overflows. In addition 0.5 ton P discharges at the tunnel overflows if the tunnel is used as a retention basin, but if the tunnel is not used as a retention basin, 6.5 tons P discharge at the tunnel overflows. This is a large amount compared to the 20 tons from the treatment plant. The reason for this is that the treatment plant's effluent is discharged to the deeper fjord layers at a constant rate, while the discharges of the overflows enter the surface layer of the fjord as shock loads.

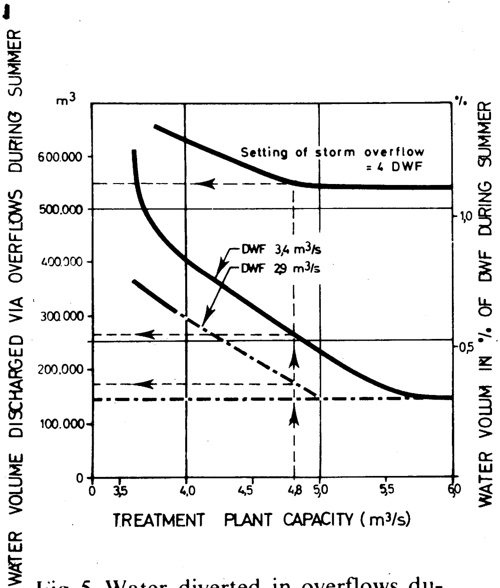

Fig. 5. Water diverted in overflows during summer.

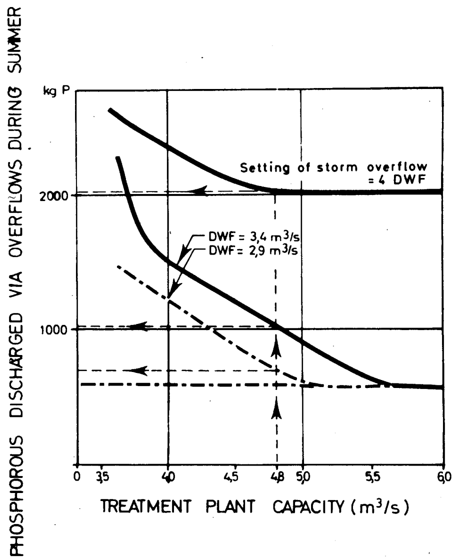

Fig. 6. Phosphorus diverted in overflows during summer.

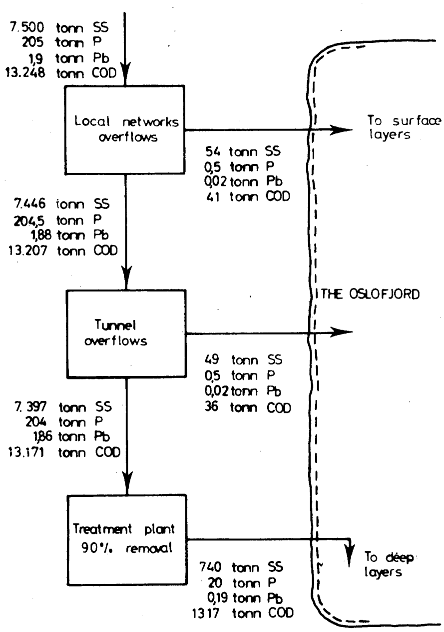

Fig. 7. Mass balance for the summer season. Retention basin in the tunnel.

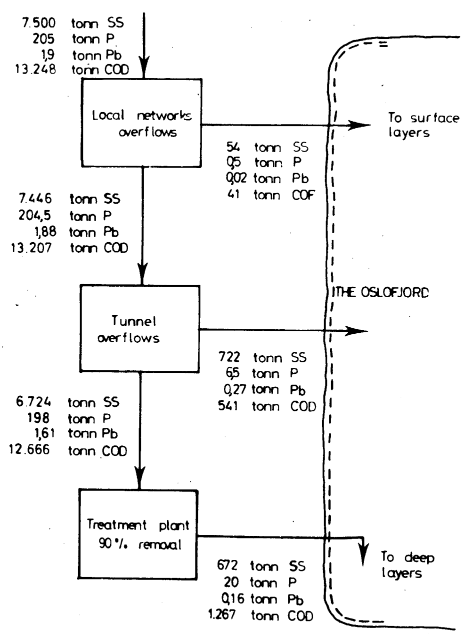

Fig. 8. Mass balance for the summer season. No retention basin in the tunnel.

Summary

Discharges of phosphorus from wastewater to the surface layers of the Oslofjord deteriorate the water quality. To alleviate the pollution it is planned to transport wastewater to a central treatment plant by a 35 km tunnel system. As the catchment mainly is served by combined sewers, the treatment plant capacity had to be large. The objective of the study was to analyze the consequences of a reduced treatment plant capacity vs. the utilization of the tunnel as a retention basin.

The analysis was performed by the use of a recently developed model for urban runoff and drainage. Data on runoff coefficients and storm water pollution were available from ongoing research projects. Simulations were performed for large rain events and for all rains during a summer season. This was feasible by the use of a computer programme that processes existing long time rain data into a minor number of base rainfalls.

The impact of storm overflows, volume of retention basins, outlet discharge from the retention basins and different rain events on the hydrograms were analyzed. The impact of storm overflow settings, volume of retention basins, outlet discharge from retention basins, different rain events and different treatment plant capacities on the discharge of pollution from the storm overflows were analyzed.

The most important result of the study was that the treatment plant could be reduced to half its original capacity if the tunnel was utilized as a retention basin without any increase, in fact a decrease, in the total pollution load on the fjord.

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Received: 12 September, 1977

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