PAPER 7

Modelling of Dunnswood STW Using STOAT

by

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INTRODUCTION

This paper provides an example of how the results of process modelling can help a regulator and a water utility solve a problem in a way which is beneficial to both parties.

Dunnswood STW is owned and operated by the West of Scotland Water (WOSW). The works was built in 1957 to serve part of the population of Cumbernauld New Town, and effluent from the works is discharged almost on an east-west watershed into a small stream known as the Red Burn which eventually reaches the Firth of Forth. The Red Burn affords very little dilution and the original consent conditions imposed by the Forth River Purification Board (now SEPA) involved limits on BOD and suspended solids of 7 mg/l and 10 mg/l respectively. The Dunnswood plant is of conventional design with primary sedimentation and activated sludge installed in two parallel streams. Each activated sludge aeration tank is divided into 5 compartments in series. For a variety of reasons the plant now serves a population equivalent of about 26,000 (including about 2000 PE from industrial sources) which is much less than the design value. Consequently the works DWF is also much less than the design value.

The FRPB have been concerned about ammonia nitrogen concentrations in the Red Burn for many years and it was recently made clear that they intended to impose an ammonia consent on the Dunnswood effluent (5 mg/l NH_4-N, 95%-ile). Strathclyde Regional Council (one of the predecessor organisations which formed WOSW) had undertaken trials which showed that partial nitrification was possible but that operation became unstable if complete nitrification was attempted.

Summary of the Problem

At the time the work described in this paper was started the problem at Dunnswood could be summarised as follows:

- An effluent ammonia consent was to be imposed at the works which was not originally designed to achieve nitrification.
- The works was not operating at design flow and load.

Flowrates were as follows:

DWF	75 l/s
Average flow	100 l/s
Max flow to secondary treatment - '3 DWF'	300 l/s

The comparison of actual DWF with the design value of '3DWF' gives an indication of the spare capacity available. The retention time in the aeration tanks was about 13h, based on DWF, suggesting that nitrification might be possible.

- Operational trials had shown that partial nitrification could be achieved but effluent quality was affected by settling tank overload, washout of MLSS during storm events and low winter temperatures.

Programme of Investigation

WOSW asked WRc to provide advice on the modifications required at Dunnswood to achieve nitrification, with the constraint that best use was made of the existing assets and additional capital expenditure was kept to a minimum. A staged approach was proposed consisting of the following activities:

- An intensive programme of sampling and analysis of wastewater at various points in the treatment process. This procedure provided data for building a model of the works to enable process simulation to be performed.
- Initial process simulations - these were performed to calibrate the Dunnswood works model, provide guidance on works modifications before the start of a full-scale experimental programme and to direct the course of the experimental programme.
- Experimental programme - this involved making incremental changes to the operational parameters of the works in order to achieve nitrification. of process.
- Further process simulations - following the experimental programme further simulations were performed to investigate the performance of the plant during simulated rainfall events and reduced temperatures.

A steering group comprising members from WOSW, SEPA and WRc was set up at the start of the programme to direct the course of the work.

Data Collection

The amount of information on wastewater characteristics and plant operating conditions which is routinely collected at treatment plants is often inadequate for process simulation or for any other form of detailed performance investigation. It is usually necessary to collect additional data by organising an intensive survey. Experience has shown that a period of about 3 weeks is sufficient providing samples are obtained every day. It is important to measure wastewater characteristics not only in the crude sewage and final effluent but also at each intermediate process stage. It is also necessary to obtain information on the diurnal variation of important parameters such as flow BOD, COD, SS, NH_3-N and KjN to enable accurate dynamic models of processes to be built.

In addition to wastewater characteristic data, process simulation also requires information on plant dimensions and operation conditions. The former are readily available but information on operating conditions in activated sludge plants can normally be usefully enhanced by further data collection during wastewater sampling programmes.

At Dunnswood, where the problem under investigation was based on the activated sludge plant performance, it was possible to simplify the data collection exercise by obtaining information from settled sewage and final effluent samples only. Composite samples were analysed for BOD, KjN, ammonia nitrogen, suspended solids and oxidised nitrogen. Diurnal variation profiles were developed by hourly sampling for flowrate, BOD, suspended solids, ammonia nitrogen and KjN.

Initial Simulations

A model of the existing Dunnswood activated sludge plant was built using the STOAT software. Data collected during the sampling programme was used to provide the inputs required for simulation and the results were compared with actual plant performance. The activated sludge aeration tanks were modified at this initial stage by incorporating anoxic zones at the tank inlet in order to promote operational stability. The anoxic zones were included in the subsequent modelling. Simulation of the plant performance during the operating regimes proposed for the experimental programme was also performed.

Experimental Programme

The experimental programme at Dunnswood consisted of a number of stages whereby the aeration tank MLSS was increased in incremental steps of about 500mg/l. Each step was separated by about one months operation under closely monitored conditions. The objective was to achieve nitrification by a gradual, controlled reduction in the sludge loading rate (SLR). The actual results of each stage of the programme are summarised in Table 1. Each row gives average results which refer to a successive stage in the programme.

Table 1 - Summary of Dunnswood Experimental Results

Sewage Flowrate (m^3/d)	MLSS (mg/l)	SLR (d^{-1})	BOD (mg/l)		NH_4-N (mg/l)		NO_2-N Eff (mg/l)	NO_3-N Eff (mg/l)
			Influent	Effluent	Influent	Effluent		
10800	1450	0.21	92	7	21	16	-	-
8200	2200	0.19	128	7	34	28	-	-
7600	2900	0.11	131	9	34	30	-	-
7500	3250	0.09	133	7	29	14	0.1	1.7
7400	3400	0.08	108	26	28	1.2	0.3	6.0

The actual results were in good agreement with modelling predictions. Table 1 shows the onset of nitrification at an SLR of about $0.09d^{-1}$ and complete nitrification at an SLR of about $0.08d^{-1}$. The results also show the effect of the aeration tank anoxic zones in reducing effluent nitrate concentrations by denitrification.

Further simulations

The results of the experimental programme provided convincing evidence that process simulation could accurately predict actual plant performance under changing operating conditions. Consequently both WOSW and SEPA were prepared to accept that further simulations could provide information on performance under purely theoretical conditions of operation.

Further process simulations were therefore performed to predict the performance of the plant under conditions which are know to affect nitrification. These conditions involved various combinations of storm event and low temperature. Rainfall adversely affects nitrification by 'washing out' MLSS from the aeration tank into the final settling tank and perhaps into the plant effluent. The system hydraulic retention time is also reduced during a storm. The micro-organisms which are responsible for nitrification are slow growing and their loss often results in a long recovery time before effluent quality is restored. The reaction rates for nitrification are also very sensitive to temperature and the mean winter temperature of sewage is often the limiting factor which influences the design of a nitrifying activated sludge plant.

Storm events were simulated by imposing a 'one-off' 300 l/s (3DWF) influent flow lasting for 6 hours onto the 'normal' diurnal flow variation established by the sampling programme. The response of the plant to these inputs was assessed by simulating performance for a 30 day period. Typical simulation results are given in Tables 2 and 3 (BOD, SS, NH_4-N results are all effluent quality in mg/l).

Table 2 - Simulation Results from 300 l/s Storm Event - Temperature 11ºC

	Before Storm Event				During Storm Event			
	Flow (l/s)	BOD	SS	NH_4-N	Flow (l/s)	BOD	SS	NH_4-N
Mean	100	1.9	3.1	1.6	300	14.5	42.2	8.6
Max.	133	3.8	4.7	3.1	300	98.9	43.9	25.7
Min.	40	0.9	1.0	0.1	300	0.4	0.9	0.1

Table 2 shows that the simulated storm event results in massive MLSS washout from the final settling tank. Effluent quality is not within consent and nitrification has been lost. Detailed simulation results showed that the plant took over one day to recover from the effects of the storm. It soon became apparent that the available settling tank capacity at Dunnswood was a limiting factor and the effect of additional final tanks are simulated.

Table 3 - Simulation Results from 300 l/s Storm Event, Temperature 7ºC
Two additional final Settling Tanks

	Before Storm Event				During Storm Event			
	Flow (l/s)	BOD	SS	NH_4-N	Flow (l/s)	BOD	SS	NH_4-N
Mean	100	2.0	2.2	0.9	300	1.0	1.9	1.6
Max.	133	2.2	2.8	1.7	300	3.1	5.4	4.7
Min.	40	0.2	0.2	0.8	300	0.2	0.4	0.1

Table 3 represents a reasonable approach to the worst conditions likely to occur at Dunnswood in the normal course of operation. The results showed that the installation of two additional final tanks should allow effluent quality to be maintained within consent conditions.

Overall Results and Conclusions

At the conclusion of the experimental programme described previously WOSW continued to operate the Dunnswood plant so that nitrification was achieved. As a result a dramatic reduction in ammonia concentration in the Red Burn was observed which complied with the EQS.

The importance of maintaining receiving water quality at this level was such that SEPA agreed to a reduction in flow to full treatment at Dunnswood from 300 l/s to 225 l/s. The results of the extensive process simulation programme provided convincing evidence that increased stormwater overflow events would be more than compensated for by stable operation of the secondary treatment plant.