© IWA Publishing 2012 Water Science & Technology | 65.8 | 2012

Integrated modelling of sewer system and wastewater treatment plant for investigating the impacts of chemical dosing in sewers

K. R. Sharma, S. Corrie and Z. Yuan

ABSTRACT

Chemicals are often dosed to control the production and accumulation of hydrogen sulfide in sewers. The biological and/or chemical actions of these chemicals have profound impacts on the composition of wastewater entering a WWTP, thereby affecting its performance. In this paper, an integrated modelling methodology for simultaneously investigating the effects of dosing of chemicals in sewer network and N and P removal at the downstream WWTP is reported. The sewer system is modelled using a sewer model (SeweX), and the WWTP is modelled using ASM2d model with some modifications. The importance of integrated modelling in sewer management is also demonstrated.

Key words | integrated modelling, sewer, sulfide, wastewater treatment

K. R. Sharma (corresponding author)
Z. Yuan
Advanced Water Management Centre,
The University of Queensland,
St Lucia, QLD 4072,
Australia
E-mail: *keshab@awmc.uq.edu.au*

S. Corrie
Allconnex Water,
Gold Coast, QLD,
Australia

INTRODUCTION

Hydrogen sulfide, which is produced by sewer biofilm as a result of sulfate reduction under anaerobic conditions, has long been identified as a major cause of corrosion and odour problems in a sewer system. In order to mitigate these problems, dosing of different chemicals to wastewater is widely used by industry. Oxygen/air, nitrate salts, iron salts and magnesium hydroxide are the commonly used chemicals. The oxygen and nitrate create aerobic/anoxic conditions in sewers and prevent the anaerobic conditions responsible for sulfide production. In addition to this, both oxygen and nitrate can oxidize sulfide that is already present biologically and/or chemically. Iron salts remove sulfide by precipitating it into insoluble iron sulfide, while magnesium hydroxide is used to elevate sewage pH, thereby minimizing the transfer of hydrogen sulfide gas into the sewer atmosphere. The chemicals that are added to sewers not only prevent the production of sulfide and its release, but also participate in other biochemical reactions, thereby changing the composition of wastewater entering the downstream wastewater treatment plant (WWTP). As some of these changes are critical to the performance of the WWTP, the addition of chemicals is expected to have significant impacts on WWTP performance, as shown in Table 1. Some of the chemicals would be beneficial (for example the use of Fe^{2+} bound in FeS helps in chemical phosphate precipitation), while others would have negative impacts. For example, addition of nitrate and oxygen reduces the amount of available carbon source for biological nitrogen and phosphorus removal in WWTP requiring additional input of the carbon source.

It has been a common practice to assess the performance and cost effectiveness of different options of chemical dosing based on the controlled sulfide levels at the end of the sewer system (de Haas *et al.* 2008). As such, the impacts of changes in wastewater composition due to chemical dosing on the WWTP performance are typically ignored in designing the sulfide control measures in sewers. A careful consideration of these effects is needed to have a realistic comparison and a better selection of the available options for sulfide control. However, to the best knowledge of the authors, no methodology or tool to achieve such a comprehensive investigation is reported in literature.

This model-based study was carried out to investigate the overall performance of network dosing of chemicals taking into account both the control of sulfide at the targeted location and the WWTP performance in terms of N and P removal. A sewer network in Gold Coast (Australia) was used as the case study.

doi: 10.2166/wst.2012.019

Table 1 | Effects of chemical dosing in sewer and WWTP

Chemicals	Effects on sewer	Changes in WW composition	Impacts on WWTP
Oxygen and nitrate	Prevents development of anaerobic conditions, oxidizes sulfide already present	Consumption of organic matter (COD)	Availability of carbon source is reduced, which is likely to impact nutrient removal
Ferric chloride	Precipitates sulfide in sewer forming insoluble precipitate (FeS)	Some COD reduction due to precipitation of colloidal organic matter is possible, presence of FeS	Oxidation of FeS under anaerobic conditions releasing Fe^{3+}, which can be used for phosphate precipitation (Gutierrez *et al.* 2010)
Magnesium hydroxide	Elevation of pH in sewer, shifts sulfide equilibrium to HS^- and prevents H_2S release	Increase in alkalinity	Possible improvement of nitrification Possibility of struvite formation

MATERIALS AND METHODS

Elanora WWTP in Gold Coast, Australia, which receives domestic wastewater from three sewer systems, namely C27, B49 and B9, was used as the case study. Details of the three sewer systems are shown in Table 2. The combined average flow from these three sewer systems is 25.9 ML/day. The WWTP is designed for biological carbon and nitrogen removal and chemical phosphorus removal. Ferric chloride is currently being used for phosphate precipitation.

The work was accomplished primarily by integrated modelling of sewer system and wastewater treatment plant. The UQ Sewer Model (SeweX), previously calibrated with the data collected from the same sewer system (Sharma *et al.* 2008a, b), was used for simulating the sewer system for four different cases of chemical addition, namely oxygen, nitrate, magnesium hydroxide, and ferric chloride. The model describes biological, chemical and physical processes that occur in the sewer system, and can be used to investigate temporal and spatial variations of sulfide production in rising or gravity main sewers. Furthermore, the model is capable of predicting changes in wastewater composition including pH with or without chemical dosing. The model doesn't consider the deposition of solids and precipitates in sewer pipes. This finding is based on the assumption that the sewer pipes are designed for non-silting velocity. However, sedimentation and re-suspension is a common phenomenon in sewers, and it is likely to have some impacts on anaerobic activity therein. Neglecting sedimentation might result in underprediction of sulfide levels as the increase of biomass due to sedimentation is neglected. Flow data for the sewer system was either calculated using supervisory control and data acquisition (SCADA) data and verified with field measurement, or imported from a calibrated hydraulic model.

Table 2 | Details of the sewer systems

		Pipe length (km)			
Sewer system	Pipe size (mm)	Rising main sewer	Gravity sewer	No. of pumping stations	Daily flow (ML)
C27	100–600	22.6	0.0	13	15.2
B49	100–1,050	6.3	1.4	22	9.1
B9	100–375	7.6	1.7	9	1.6
Total	100–1,050	36.5	3.1	44	25.9

The chemical dosing locations and rates were optimized taking into account the contribution of all the three sewer systems in terms of sulfide load to the WWTP inlet and the combined level of sulfide at the WWTP inlet. The sewer model was used to determine the composition of wastewater entering the WWTP under the dosing of each of the chemicals studied.

Activated Sludge Model No. 2d (ASM2d) including the model parameter values therein (Henze *et al.* 2000) was employed to assess the impacts on the performance of the WWTP in terms of nutrient (N and P) removal. It has been reported that some of the parameters of ASM2d, especially those related to nutrient removal, are not accurate and require some modification (Gernaey & Jørgensen 2002). For simplification, default parameters were used for making comparison of the impacts of chemical dosing under different dosing conditions. Additional components were added to the ASM2d model to take into account the processes relevant to $FeCl_3$ dosing (Gutierrez *et al.* 2010). The SeweX and ASM2d models use very similar state variables characterizing the composition of wastewater so that the interface between the two models was conveniently developed. However, certain assumptions were made while estimating the concentrations of different COD fractions. These assumptions include: (1) inert fractions of both particulate and soluble COD were assumed to be typical of domestic wastewater; (2) fermentable COD and the COD of fermentable products were considered to be same as in the sewer model; and (3) the slowly biodegradable COD was assumed to be the sum of the concentrations of fast and slowly hydrolysable substrates in the sewer model.

RESULTS AND DISCUSSION

The variation of flow in the three sewer systems is illustrated in Figure 1. A number of simulations were carried out to arrive at the optimized dosing location and rate for each of the chemicals separately by considering the dissolved sulfide discharge at the WWTP inlet. The choice of the location of the dosing site was somewhat limited due to availability of land and the essential facilities for installing the dosing equipment. The dosing locations and rates for each of the four chemicals studied here are presented in Table 3.

Table 3 | Location and rates of dosing of the chemicals

Chemical	Sewer system	Location (distance from the WWTP) (km)	Dosing rate
Oxygen	C27	1.8	195 kg O_2/day
	B49	5.1	234 kg O_2/day
	B9	1.3	24 kg O_2/day
Calcium nitrate	C27	1.8	72 kg N/day
	B49	5.1	164 kg N/day
	B9	1.3	17 kg N/day
Magnesium hydroxide	C27	10.6	365 kg $Mg(OH)_2$/day
	C27	16.6	550 kg $Mg(OH)_2$/day
Ferric chloride	C27	0.5	260 kg Fe^{3+}/day
	B49	5.1	94 kg Fe^{3+}/day
	B9	5.2	34 kg Fe^{3+}/day

The sulfide levels at the WWTP inlet, which is the point of interest in this case as the location is experiencing an odour problem, were estimated for different cases of chemical dosing. The results shown in Figure 2 demonstrate that the proposed dosing of oxygen, nitrate and ferric chloride was effective in controlling the dissolved sulfide levels to an average of 1 mg S/L. Taking into consideration both the mixing and ventilation conditions at the WWTP inlet, this level of dissolved sulfide was considered to be acceptable for the control of odour and corrosion control. With the dosing of magnesium hydroxide, the average hydrogen ion

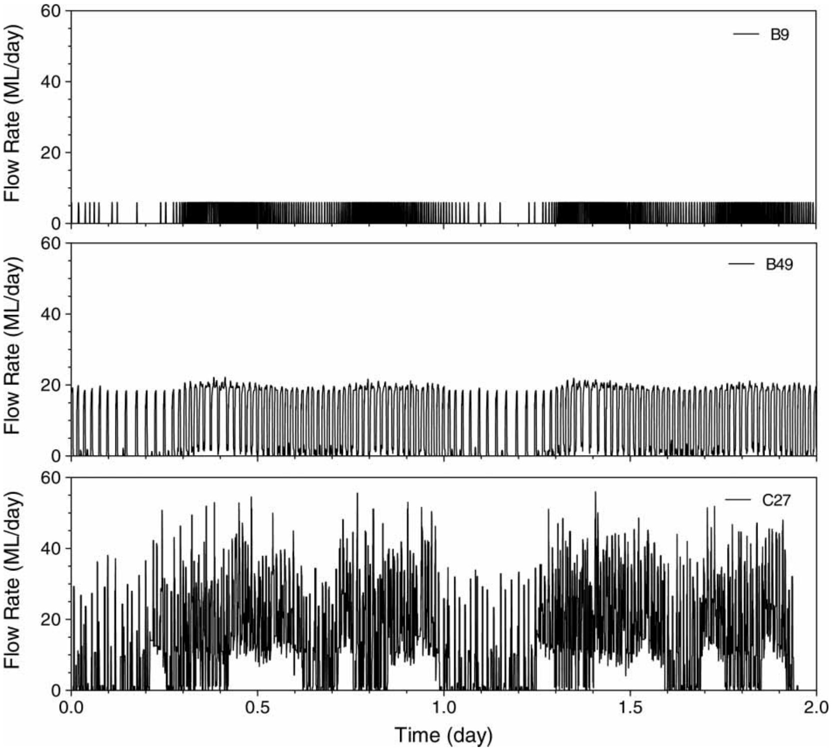

Figure 1 | Variation of flow in the three sewer systems.

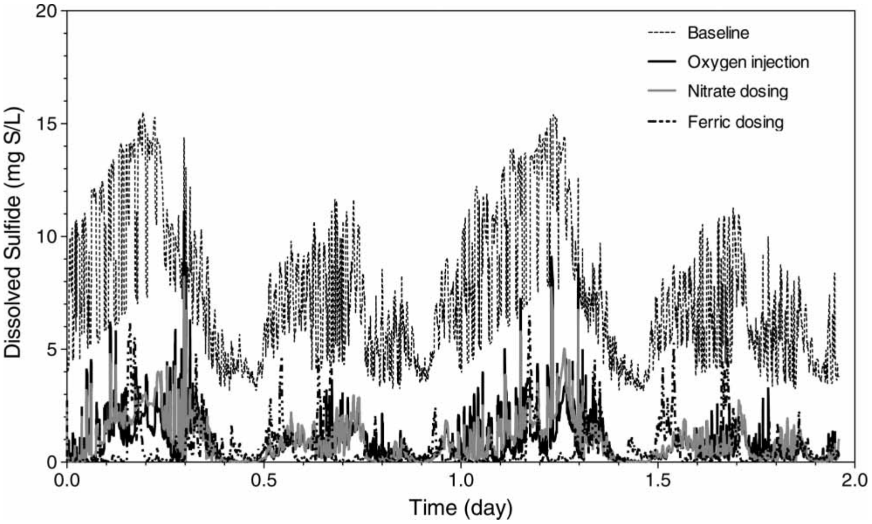

Figure 2 | Dissolved sulfide levels at WWTP inlet with the dosing of different chemicals.

concentration at the WWTP inlet could be raised to 3.3×10^{-9} giving a pH of 8.5. The conventional approach would be to consider the cost of chemicals required to achieve the target sulfide or pH level at the point of interest and make the selection of the most cost effective option, as demonstrated in de Haas *et al*. (2008). However, this approach has some serious limitations, as will be discussed later.

Availability of a readily biodegradable carbon source such as volatile fatty acids (VFA) is key to the nitrogen and phosphorus removal in a WWTP. In addition, dosing of iron salts is needed to supplement the phosphorus removal in a case where the plant is designed for biological phosphorus removal or to precipitate phosphate in other cases.

Oxygen and nitrate both oxidize the hydrogen sulfide produced in sewer biofilm. Sulfide is oxidized both chemically and biologically with oxygen, while nitrate can only oxidize it biologically. The rate of sulfide oxidation with nitrate is thus lower than that with oxygen, especially in large pipes where chemical oxidation plays a major role. Consequently, nitrate requires a longer contact time for complete sulfide oxidation as compared with oxygen. In addition to the oxidation, both oxygen and nitrate promote heterotrophic activity in biofilm, thereby oxidizing a significant amount of organic matter in sewage. The

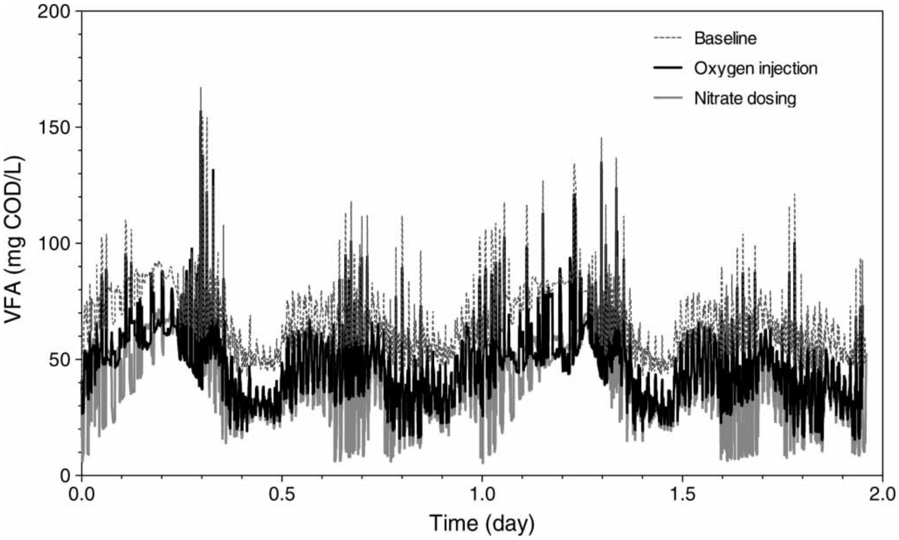

Figure 3 | Changes in VFA concentration in WWTP feed due to oxygen and nitrate dosing.

addition of both oxygen and nitrate resulted in reduced levels of volatile fatty acids (Figure 3). The impact was much more pronounced in the case of nitrate than oxygen. Simulation results revealed that, compared with oxygen, a much larger amount of nitrate (in terms of electron accepting capacity) was required to achieve the same level of sulfide control, resulting in more consumption of organic carbon through denitrification. This is due to the longer contact time required for nitrate as explained above.

The dosing of magnesium hydroxide caused the elevated pH levels (Figure 4). The overall production of sulfide is also lower in this case due to the inhibition of sulfate reducing bacteria in the biofilm (Gutierrez *et al.* 2009). The elevated pH conditions prevent the release of hydrogen sulfide gas to the atmosphere responsible for the odour and corrosion problems.

Dosing of ferric salts resulted in hydrogen sulfide precipitation in the form of FeS precipitates (Figure 5), which would enter the WWTP. Laboratory studies reported in Gutierrez *et al.* (2010) have shown that a negligible fraction of FeS particles will be retained in the primary settling tank in this case as the $FeCl_3$ was dosed close to the WWTP inlet, resulting in a short contact time insufficient for FeS colloids to form large sized particles. Once the FeS particles enter the WWTP, FeS precipitates get oxidized to Fe^{3+} and SO_4^{2-} in the aeration tank and the Fe^{3+} thus formed results in the precipitation of PO_4^{3-} (Gutierrez *et al.* 2010).

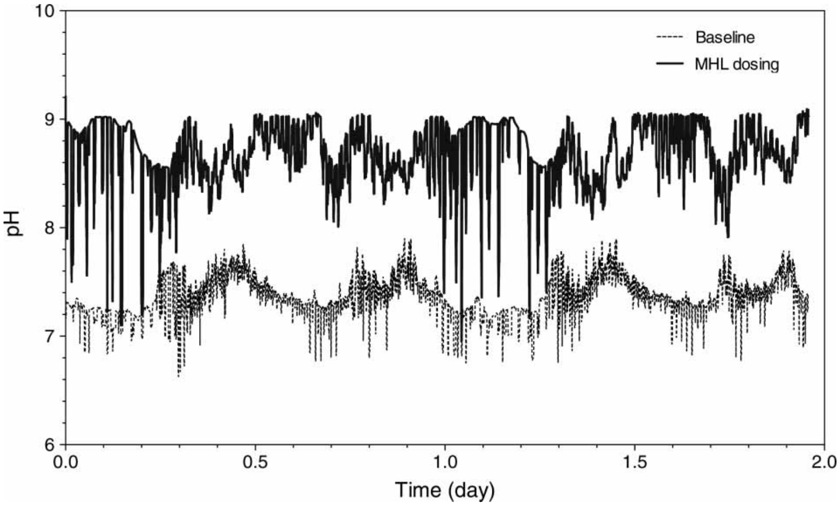

Figure 4 | Change in pH due to magnesium hydroxide dosing.

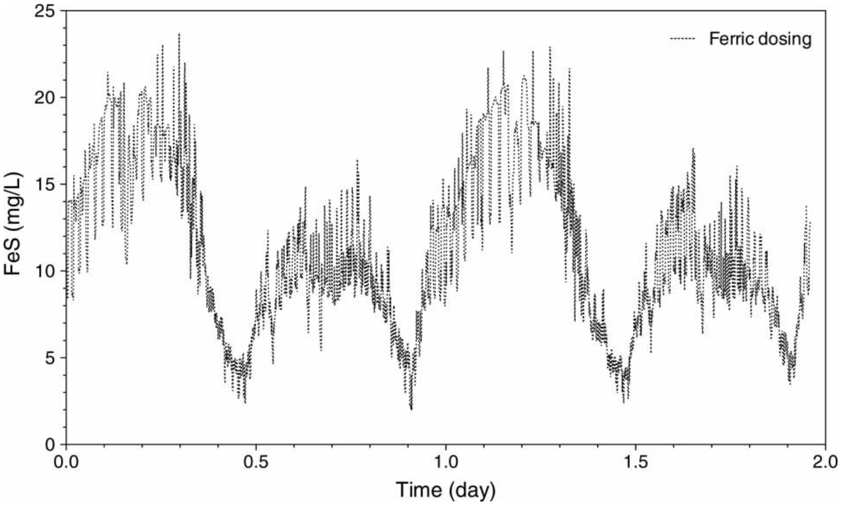

Figure 5 | FeS levels in the WWTP feed under ferric chloride dosing.

The results show a high variability in the concentrations of simulated water quality parameters, which is mainly due to the variation of flow in each of the sewer systems modelled. As the results further elucidate, optimizing the chemical dosing for such a dynamic system is not straightforward, and the control of sulfide with chemical dosing is not always optimal.

The results of WWTP simulation are presented in Figures 6 and 7. Addition of oxygen and nitrate caused additional consumption of COD, especially the VFA in sewers, resulting in deterioration of N removal in downstream WWTP (Figure 6). This would require addition of a carbon source (for example acetate) in the WWTP to improve N removal performance, thereby adding to the operational cost of sulfide control. FeS precipitates formed as a result of Fe^{3+} dosing in the sewer were found to enhance the phosphorus removal in the WWTP (Figure 7). Amount of ferric added to the sewer was found to be sufficient to achieve effluent phosphate level of <1.0 mg P/L.

The impacts of elevated pH on biological activities in the WWTP were not considered. It is assumed that the pH level of around 8.5 will not have any significant impacts on biological N removal. The addition of $Mg(OH)_2$ and the resulting higher pH can result in the formation of struvite ($MgNH_4PO_4{\cdot}6H_2O$), which may cause problems due to its precipitation in pipes. The precipitation of struvite can be considered to occur when the product of activities of magnesium, ammonium and phosphate ions exceeds

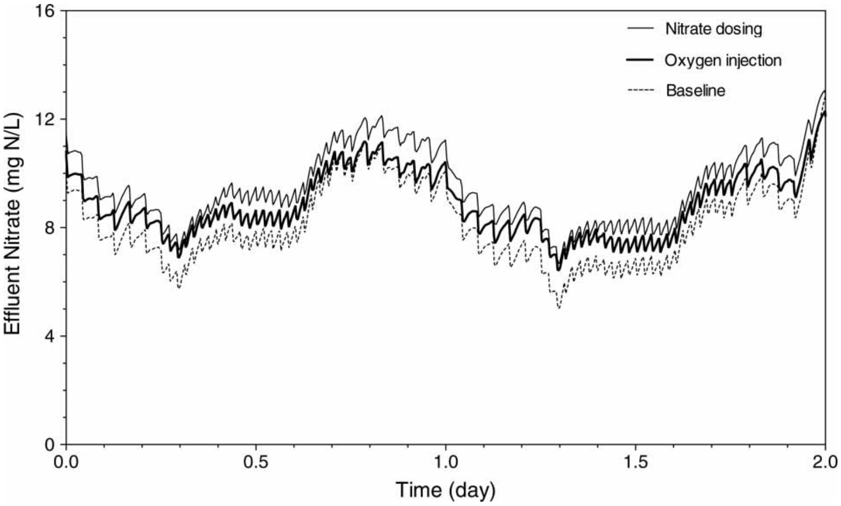

Figure 6 | Impacts of oxygen and nitrate dosing on nitrogen removal in WWTP.

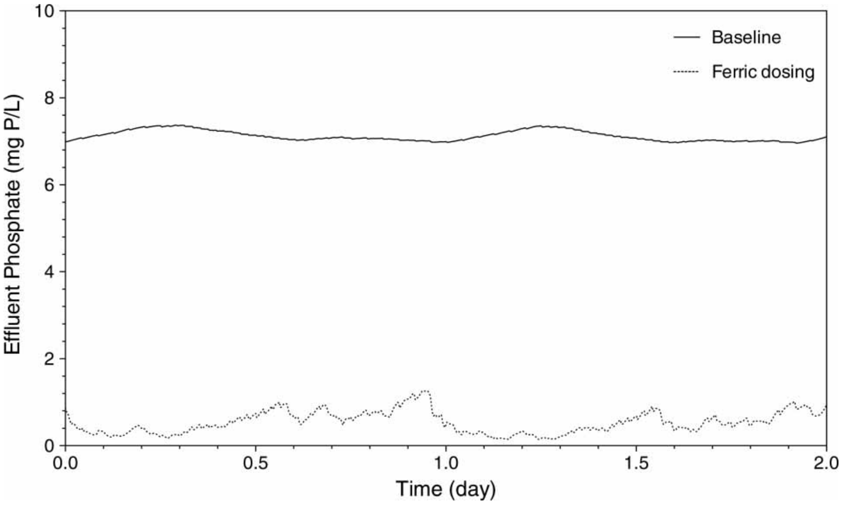

Figure 7 | Impacts of ferric dosing on phosphate removal in the WWTP.

thermodynamic solubility product (Ksp) of struvite (Bhuiyan *et al.* 2008). With typical levels of phosphate (~7 mg P/L) and ammonia (~50 mg N/L) in domestic wastewater, struvite precipitation is likely to occur only at pH above 9 when magnesium hydroxide is dosed in excess. The amount of struvite is therefore not expected to be significant in this case. However, when the waste activated sludge with such a high pH is subjected to anaerobic digestion, a number of significant changes are likely to happen, such as drop of pH due to the production of volatile fatty acids, and increase in both phosphate and ammonia nitrogen levels. These conditions could lead to the formation of struvite in this anaerobic digestion unit. However, this was not considered in this study.

CONCLUSIONS

Dosing of chemicals to sewers has significant impacts on N and P removal in WWTP. The addition of oxidants such as oxygen and nitrate oxidizes available carbon in wastewater and hence affects the N removal. This phenomenon will be critical in cases where the N removal is limited by the availability of carbon source. $FeCl_3$ addition on the other hand can be used to precipitate phosphate chemically. The double use of ferric to precipitate sulfide in sewers and phosphate in WWTP will provide significant cost savings. The approach presented here can be used to make a comparison of overall operating costs taking into account both the amount of chemical dosed to sewer and any additional chemical required to enhance the nutrient removal. This study demonstrated the need of integrated modelling for the assessment of options of chemical dosing in sewers. Furthermore, sewer and WWTP models have been illustrated as valuable tools for optimal sewer management.

ACKNOWLEDGEMENT

The authors would like to thank Allconnex Water for their financial support.

REFERENCES

Bhuiyan, M. I. H., Mavinic, D. S. & Koch, F. A. 2008 Phosphorus recovery from wastewater through struvite formation in fluidized bed reactors: a sustainable approach. *Water Science and Technology* **57** (2), 175–181.

de Haas, D. W., Sharma, K., Corrie, S., O'Halloran, K., Keller, J. & Yuan, Z. 2008 Odour control by chemical dosing: a case study. *Water (Journal of AWA)* **35** (2), 138–143.

Gernaey, K. & Jørgensen, S. B. 2002 Benchmarking combined biological phosphorus and nitrogen removal wastewater treatment processes. *Control Engineering Practice* **12**, 357–373.

Gutierrez, O., Park, D., Sharma, K. R. & Yuan, Z. 2009 Effects of long-term pH elevation on the sulfate-reducing and methanogenic activities of anaerobic sewer biofilms. *Water Research* **43** (9), 2549–2557.

Gutierrez, O., Park, D., Sharma, K. R. & Yuan, Z. 2010 Iron salts dosage for sulfide control in sewers induces chemical phosphorus removal during wastewater treatment. *Water Research* **44**, 3467–3475.

Henze, M., Gujer, W., Mino, T. & van Loosdrecht, M. 2000 *Activated sludge models ASM1, ASM2, ASM2d and ASM3.* IWA Scientific and Technical Report No. 9. IWA Publishing, London.

Sharma, K. R., Yuan, Z., de Haas, D. W., Hamilton, G., Corrie, S. & Keller, J. 2008a Dynamics and dynamic modelling of H_2S production in sewer systems. *Water Research* **42** (10–11), 2527–2538.

Sharma, K., de Haas, D. W., Corrie, S., O'Halloran, K., Keller, J. & Yuan, Z. 2008b Predicting hydrogen sulfide formation in sewers: a new model. *Water (Journal of AWA)* **35** (2), 132–137.

First received 5 September 2011; accepted in revised form 29 November 2011