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Screening for real-time control potential of urban wastewater systems

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Abstract

The paper describes the application of the model SYNOPSIS to the integrated modelling of urban wastewater systems. The aim was to develop a screening procedure to establish the real-time control potential (RTC) of an urban catchment without the necessity of carrying out a detailed modelling assessment procedure. SYNOPSIS was applied to a series of 'related' catchments (with and without real-time control) that were similar in most respects but had differences in key parameters such as total storage volume and river dilution. It was found feasible to linearly regress control potential based on a river minimum dissolved oxygen concentration with the magnitude of these parameters. Extending the application of the procedure showed that optimisation for DO performance did not necessarily reduce river ammonia concentrations and could in fact increase them. Widening the parameter space was shown to reduce the simplicity of the procedure and the correlation coefficients in the regressions. The procedure was successfully applied to a range of real catchments and managed to identify sites with existing RTC as having high potential.

Keywords: Integrated modelling; Optimisation; Real-time control; Screening; Urban wastewater system

1. Introduction

In many cities of the developed world, wastewater (together with stormwater in combined systems) is managed by means of a sewer system and wastewater treatment plant, discharging into a receiving water body. Often, the performance of these parts can be increased by means of control and several studies have been carried out on the control of sewer systems (Schilling, 1989, 1994), wastewater treatment plants (Olsson and Newell, 1999) and, to a lesser extent, receiving water bodies (Beck and Reda, 1994). Only recently, control considering the urban wastewater system as one entity has been analysed in detail (Meirlaen et al., 2000; Schutze, 1998; Schutze et al., 1999; Tomicic, 2000). Furthermore, simulation studies have also demonstrated that integrated control, characterised by integration of objectives

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and information exchange, can indeed lead to further increased performance of the wastewater system (Schutze et al., 1999).

The research outlined in this paper aims at the development of a screening procedure that allows the potential of real-time control of the entire urban wastewater system to be assessed. SYNOPSIS is used as the simulation engine for the simulation of the RTC options in the integrated system presented in detail by Schutze (1998) and Schutze et al. (1999, 2002a). On the basis of the RTC simulation results a screening procedure was developed referred to as the RTC Potential Calculator. This paper outlines the development of the RTC Potential Calculator and focuses on the results from on-going work aimed at enhancing it.

The definition of the wastewater system's performance used in the RTC Potential Calculator focuses on minimising the duration of critically low concentrations of dissolved oxygen DO in the river (the so-called 'DO-DU' criterion). Further work is presented where the duration of critically low ammonia–nitrogen concentrations (the AMM-DU criterion) is used as the criterion for establishing RTC potential. Comparisons are then made between the RTC potential based on DO-DU and AMM-DU criteria. Finally, an application of the tool to real wastewater systems where RTC potential has been established is also presented.

1.1. What is real-time control?

The presence of measuring devices (e.g. sampling water level, flows, concentrations) and regulating devices (e.g. pumps, gates, aerators) is common in wastewater systems in which RTC is performed. Information from measurement devices is used for describing the state of the system, which, in turn, determines the control action to be taken, according to an RTC algorithm. The proposed control action is transmitted to the regulating devices, which affect the state of the system. This is influenced by the control strategy, which outlines the fundamental principles of how control is to be performed in the system (e.g. utilisation of in-sewer storage volume). The control strategy, in turn, results from the control objectives, which are often imposed by regulations and guidelines. Schematically this is shown in Fig. 1.

1.2. Control objectives in an integrated system

Real-time control is usually applied in order to make better use of existing infrastructure. In many cases, expensive construction or expansion of the wastewater system (e.g. by provision of additional storage tanks) can be avoided by prudent utilisation of the existing storage and treatment facilities. In conventional applications of real-time control, the control objectives (for sewer systems) are often described in terms of flow volumes or pollutant loads discharged at combined sewer overflows. In operational practice, usually an additional objective is to maintain cost-efficiency. However, neither of these approaches considers the water quality of the receiving water body directly. For example, due to different dilution and degradation capacities of different receiving water bodies, the same wastewater discharged into different receiving water bodies can have different effects. Also, the timing of discharges can play an important role. A summary of the state of the art of RTC can be found in Schütze et al. (submitted)

Objectives can be based, for example, on concentrations of ammonium and dissolved oxygen. RTC objectives may also focus, possibly with lower priority, on aiming to bring the system back to 'ideal' state or on preventing it from deviating from 'ideal' state (Beck, 1999). A ranked list of potential RTC objectives is shown below (Schutze et al., 2002b)

1. Maximise the time period during which standards are adhered to.
2. Minimise the extent to which the standards are breached.
3. Maximise the recovery potential of the system.
4. Maximise the resistance potential of the system against future perturbations.
5. Improve river water quality above minimum standards.

For simplicity, however, in the present study, the objective used was initially based on the duration of critically low DO concentrations in the receiving river and later extended to account for the duration of critically high ammonia concentrations. Following the specification of control objectives, the control potential of any given system can be described as its ability to achieve the control objectives. More specifically,

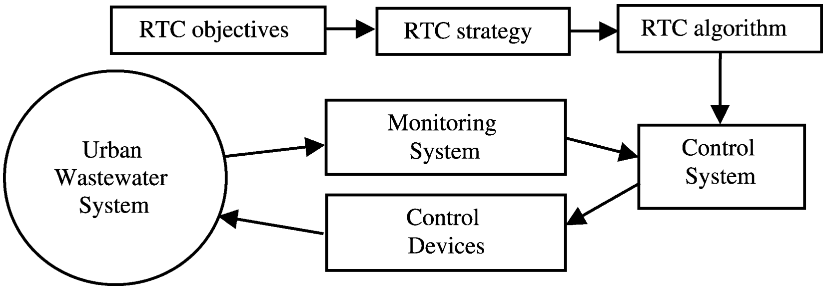

Fig. 1. An urban wastewater system operated under real-time control (Schutze et al., 2002a).

it designates the potential to improve the systems' performance by means of real-time control. Improvement of the potential is measured against the performance of the system at a reference scenario (e.g. a base-case of static control).

1.3. What is RTC potential?

The control potential of any given system can be described as its ability, by means of real-time control, to achieve the control objectives. The definition of the wastewater system's performance used in this project focuses on minimising the duration of critically low concentrations of dissolved oxygen (the so-called 'DO-DU' criterion) or critically high ammonia concentration in the river (the so-called 'AMM-DU') (Schutze et al., 1999). Improvement of the potential is measured against the performance of the system at a reference scenario (e.g. a base-case of static control) and depends on the category of RTC applied (e.g. local, global or integrated).

However, prior to the actual implementation in practice, an extensive analysis including detailed modelling is usually required to assess the RTC potential for a given site. Such studies generally involve major expense, possibly resulting in the outcome that RTC is not feasible for the site under investigation. Thus, it would be desirable to be able to apply a screening procedure, which allows a relatively quick assessment to be made as to whether a system appears to gain in performance by application of RTC. The result of this assessment could then be used to justify the effort and cost of a detailed feasibility study. Earlier research has led to the provision of an easy-to-apply scoring system allowing a quick assessment of the RTC potential of controlling flow in sewer systems (Schilling, 1994). However, as this procedure neither takes into account water quality aspects, nor the treatment plant or the receiving water body, it cannot be used for assessing the potential of RTC of the complete system. Thus it was decided to develop such a screening procedure, applied to the complete urban wastewater system. Parallel work is currently underway in Germany (Schütze et al., submitted).

2. Synopsis: an integrated modelling tool

Conventionally, planning, design and operation of urban wastewater systems (UWWS) are carried out for each of its components separately. Current practice considers these components as separate units neglecting interactions between them. The importance of analysis of the entire system has been realised for some time (Durchschlag et al., 1991; Tyson et al., 1993). For example, a common approach to reduce river pollution caused by combined sewer overflows is to introduce a storage tank to temporarily store wastewater flows. The stored volume of wastewater will then be diverted back to the WWTP for treatment when there is available capacity. However, prolonged flow to the WWTP may sometimes also lead to further negative impacts on the receiving water. This is manifested not only in terms of the increase in total pollutant load discharged but also the possibility of breakdown in plant capacity (i.e. loss of secondary clarifier sludge blanket) due to shock loading (Lau et al., 2002; Rauch and Harremoes, 1996). Ideally then, interactions between the urban drainage system, treatment plant and receiving water have to be more fully considered.

However, detailed analyses of the UWWS as a whole were delayed due to the lack of appropriate simulation tools. A simulation tool, called SYNOPSIS (‘software package for SYNchronous OPtimisation and SImulation of the urban wastewater System’), has been developed, which takes the major parts of the UWWS and their interactions into account. SYNOPSIS was developed to assist studies of the urban wastewater system following the need for an integrated perspective. The simulation package consists of three main simulation sub-programs for modelling water flow and quality processes in the urban drainage system, WWTP and river system. A number of auxiliary programs are also used for control, optimisation and file management. The following is an outline description of each of the sub-models and a number of important details. A more detailed description is given by Schutze et al. (1999). Fig. 2 provides a schematic overview of the SYNOPSIS package.

The urban drainage sub-model is based on the KOSIM program (itwh, 1995). The model allows for abstraction of wetting, depression and evaporation losses from rainfall–runoff. Subsequently, flow routing within a sub-catchment (incorporating surface and pipe storage effects) is accomplished using a cascade of linear reservoirs model. Flows between sub-catchments are routed by translation only. Pollutants are considered to originate from rainfall–runoff and domestic and industrial wastewater flows and to be completely mixed throughout the drainage system. No in-sewer processes are represented, neither sediment transport nor biochemical reactions, so any first foul flush cannot be predicted. However, the quality of the wastewater discharging at the overflows is specified with a greater fraction of rapidly biodegradable BOD (in the river model) than is given to the incoming WWTP effluent. Overflows and different types of storage tanks can be specified (if required) at the downstream end of each sub-catchment.

The use of relatively simple flow and quality engines in the sewer model is sufficient for the needs of long-term continuous simulation in integrated modelling. In particular, use of a more detailed hydraulic model would lead to problems of long simulation periods and excessive amounts of data/results for analysis. More detailed quality models are available but there are still significant uncertainties and difficulties in the use of these approaches.

The WWTP sub-model is based on a slight simplification of the IWA Activated Sludge Model No. 1 (Henze et al., 1987). The model was developed by Lessard et al. (1993) and represents the main unit processes of a conventional activated sludge plant: storm tanks, primary clarifiers, activated sludge aeration tank and secondary clarifier. Quality parameters include SS, VSS, COD (in various fractions), NH_3-N and NO_3-N. These data are taken from the output of the urban drainage sub-model.

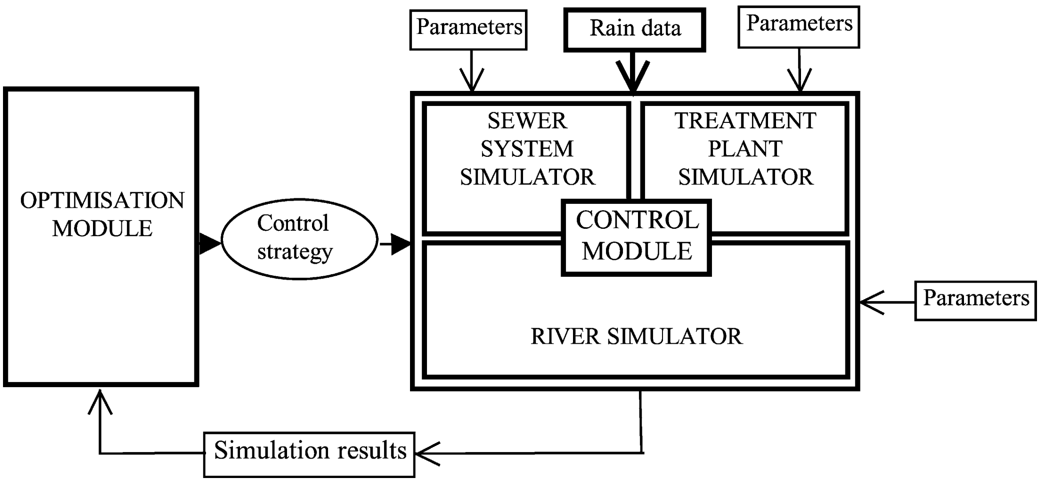

Fig. 2. Overview of SYNOPSIS (Schutze et al., 1999).

The river sub-model is based on the DUFLOW shell program (IHE, 1992). The river hydraulics are represented by solving the St. Venant equations using a four-point implicit Preissmann scheme. Pollutant mass transport is modelled using the advection–diffusion equation. Representation of river water quality is based on an extension of the classic Streeter–Phelps model, including BOD (readily and slowly biodegradable fractions), NH_3-N and DO as key variables. This allows the model to characterise a number of phenomena, including reaeration, deoxygenation, nitrification, sedimentation, sediment oxygen demand and photosynthesis. Discharges into the river originate from three sources: CSO spills, storm tank overflows and treatment plant effluent. Routines convert drainage system and WWTP model quality parameters to those required for the river model. River catchment runoff is modelled by a simplified time-series approach.

The three sub-models are incorporated into one simulation program. The urban drainage system and WWTP are simulated in parallel. The river model is then run separately, as a sequential process. The programs are connected only at the necessary parts. This provides a hybrid of integrated simulation between pure sequential and parallel approaches. The simulation of the integrated system in this manner satisfies the requirements for investigating the relationship between overflows and receiving water quality.

3. Overview of the integrated catchment

The catchment used for the study is illustrated in Fig. 3 and is semi-hypothetical in origin (Schutze et al., 1999). The urban drainage system consists of a network of seven sub-catchments, based on an example in the German ATV 128 document (ATV, 1992) and rescaled to match the capacity of the WWTP. As a simplification, a single on-line storage tank is modelled at the downstream end of the urban drainage system, with a setting in accordance with Formula A (MHLG, 1970).

The WWTP is based on, and calibrated against, the UK Norwich works. The treatment plant is modelled to handle an average DWF of about 27,500 m^3/d. A storm tank with a volume of 6750 m^3 is located at the inlet of the treatment train. This provides additional storage capacity to that of the storage tank located in the urban drainage system. The storm tank starts to fill when an inflow rate of 3DWF is reached. The tank is emptied with a pump rate of 500 m^3/h when the inflow

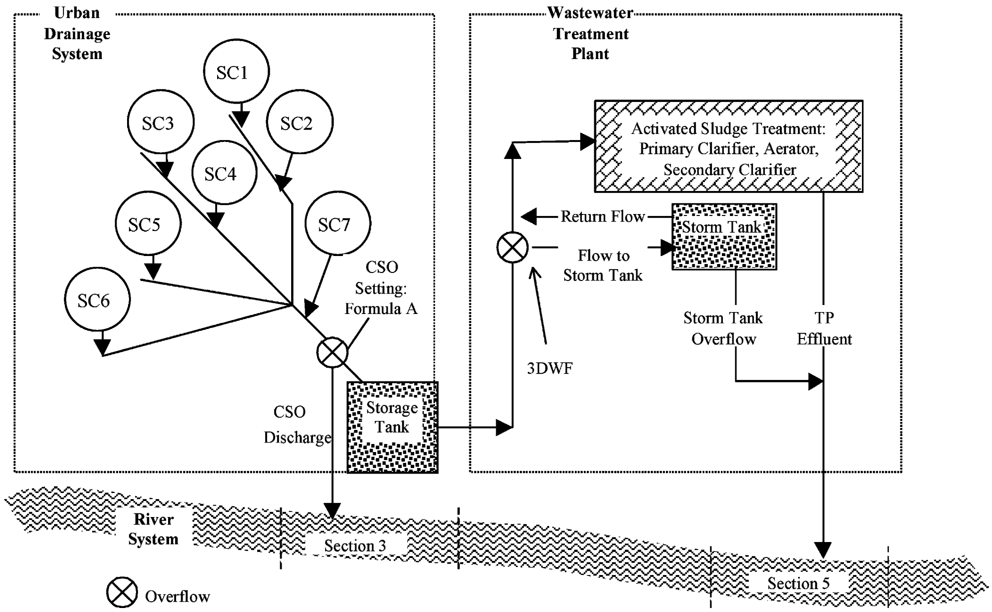

Fig. 3. Schematic representation of modelled urban wastewater system.

Table 1
Properties of the urban wastewater system relevant to RTC potential

Element of system	Property
Storage volume	Total amount and distribution of storage
Sewer network	Sewer flow time within the sewer catchment
	Catchment rainfall–runoff characteristics
	Network topology, slope, flow velocity
CSOs	Number and location of discharges of CSOs
Treatment plant	Treatment schemes and control options
Receiving water	Amount of base flow (dilution capacity)
	Variations in flow and quality of base flow
	River catchment rainfall–runoff characteristics
	Number, location and type of receiving water bodies
	Availability of prediction and spatial distribution

to the WWTP drops below a threshold value, which is determined by the control strategy implemented.

The receiving water system consists of a purely hypothetical river. The river has a base flow of 1.5 m^3/s that provides a dry weather dilution ratio of approximately 1:5. The river is discretised into 40 sections. Each section is 1 km long. Overflow spills from the urban drainage system discharge into section 3 of the river. The discharge of storm tank overflows and treatment plant effluent are combined and empty into section 5 of the river. The simulations were run with an hourly timestep.

4. Developing an RTC potential screening procedure

The screening procedure for the assessment of the RTC potential of a given urban wastewater system was developed in several stages. Initially, a list of the properties of the urban wastewater system that are believed to have significant influence on the control potential was compiled, shown in Table 1. Selected system characteristics were then subjected to a detailed simulation study, aimed at determining the relative importance of the various system parameters.

In order to derive general statements, which are valid for a wide range of case studies and topologies of UWWS, the analysis is conducted for a large number of case study sites, comprising of sewer system, wastewater treatment plant and receiving waters of different layout. For this purpose, a large number of hypothetical case study sites were generated, based on the original case study site. In order to demonstrate here the methodology embarked upon in this project, a subset of six properties has been selected from those in Table 1. Taking all possible combinations of high and low values of these six properties, 64 (2^6) hypothetical instances of UWWS have been generated, shown in Table 2.

For each of these 64 sites, two paradigms of RTC are tested: one relates to a scenario of optimised integrated control (Option 2), while the other reflects an example of base case local control (Option 0). While a detailed analysis of the control scenarios is presented in elsewhere (Schutze, 1998), their key attributes are summarised in Table 3.

Control optimisation was performed using the Shuffled Complex Evolution (Duan et al., 1992) algorithm. This is an efficient global optimisation procedure, suitable for optimisation of objective functions of complicated nature, which are not tractable by classical, gradient-based methods.

Table 2
Generation of case study sites by variation of system properties

System property	Original value	Modified value
Discharge location of treatment plant	3 km downstream of CSO (normal)	5 km downstream of CSO (further apart)
River dilution	1 in 5 (normal)	1 in 3 (low)
Catchment rainfall–runoff	As original case study (normal)	2/3 of original case study (low)
Flow time in sewer system	As original case study (long)	2/3 original case study (short)
Total storage volume	19,950 m^3 (27.5 m^3/ha) (high)	13,300 m^3 (18.3 m^3/ha) (low)
Storage distribution (total storage kept constant)	As original case study (D/S)	1/3 more storage upstream, 1/3 less storage downstream (U/S)

Table 3
Control scenarios investigated

Control scenario	Parameters considered for optimisation
0. Base case: fixed set points	None: local control is carried out with constant set points for: Pumps in the sewer system Maximum inflow to the treatment plant Flow threshold triggering emptying of the storm tank Return and waste sludge rates in the treatment plant
1. Optimised set points	As above, but the following set points are optimised: One pump in the sewer system Maximum inflow to the treatment plant Flow threshold triggering emptying of the storm tank
2. Integrated control	Hierarchical control: as before, but the set points are overridden in extreme situations

5. Results of simulations

In the present study, receiving water quality is assessed according to an approach similar to that set out in the UK Urban Pollution Management (UPM) Manuals and by Rauch et al. (1998), and a variety of standards has been used. The first edition of the UPM manual (FWR, 1994) defines concentration/duration thresholds that should not be breached beyond a specified frequency (otherwise known as Fundamental Intermittent Standards) for DO and ammonium. Based on these values, a 4 mg/l DO threshold was selected. The values for ammonium could not be used due to the limitations of the river model in representing temperature and pH. For this reason, a Derived Intermittent Standard for total ammonia of 4 mg/l was used instead.

Therefore, the optimisation aims at minimising the time periods during which the dissolved oxygen and ammonia concentrations in the river exceed the critical threshold value of 4 mg/l at any point in the river. The performance of the various systems under the integrated RTC scenario defined above has been compared with their performance under the base case scenario. Comparison of the oxygen and ammonia balance in the river under the various scenarios with the base case then allows conclusions to be drawn concerning the RTC potential of the various case studies. In the present study, RTC potential was calculated as the reduction in time periods exceeding the limits defined above, expressed as a percentage.

A summary of results is shown in Fig. 4 where the reduction in critical river DO violation frequency can be seen for each simulation run where integrated control is applied. Clearly, the level of improvement varies for each case study, but the trend is generally higher for the integrated case. Fig. 5 summarises the findings obtained for the integrated control scenario, expressed as RTC potential. Since optimisation runs were carried out for 64 different UWWS, Fig. 5 is organised in an 8-by-8 scheme, with each of the two axes representing all possible combinations of three system properties.

6. Analysis of results

It is revealing to analyse Fig. 5 for regions of high RTC potential. Ridges with high potential can be found for large amounts of total storage, combined with a relatively short distance between CSO and treatment plant location (cf. the dark region between the lines marked ‘4’ and ‘5’). A particularly large RTC potential is indicated for normal river dilution and a large total storage volume in the sewer system and wastewater treatment plant (cf. the dark region between the lines marked ‘0’ and ‘1’). A detailed statistical evaluation (Analysis of Variance) indicates the following ranking of the influence of the system properties to RTC potential (Table 4). It is not surprising that the total storage volume available within the system has significant influence on RTC potential. This has long been recognised in the design and operation of sewer systems (Schilling, 1989). However, the fact that river base flow and the location of the discharge points also have large influence

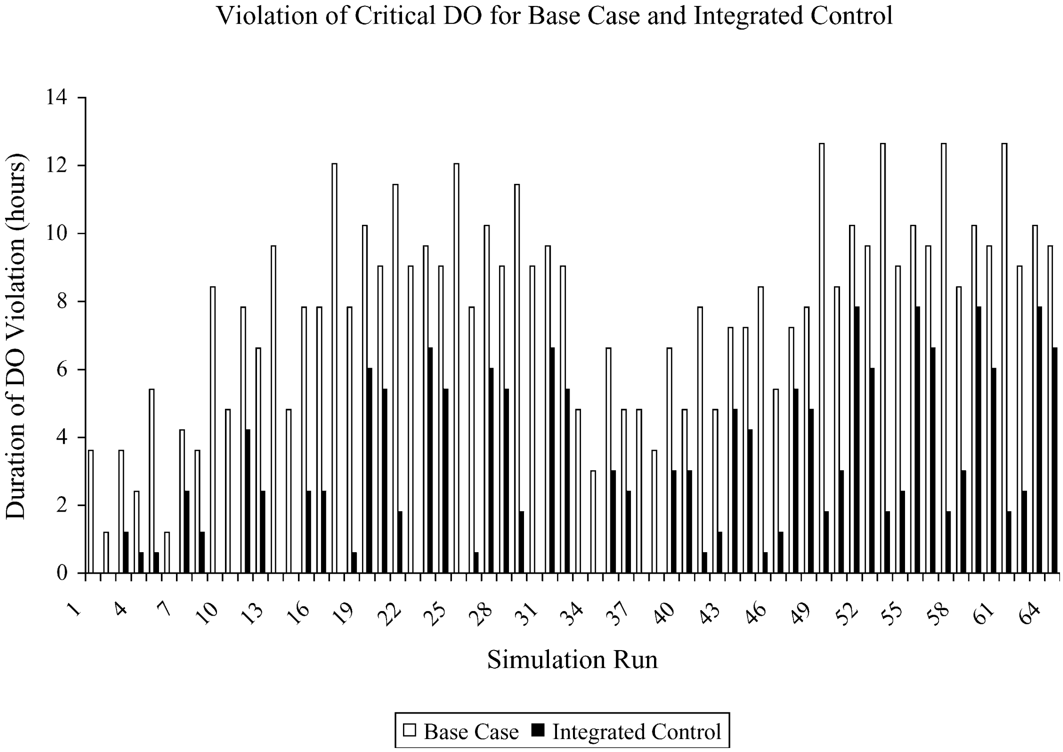

Fig. 4. Violation of critical DO for local and integrated control.

stresses the importance of an integrated approach to the analysis of UWWS.

In order to develop an easy-to-apply tool, the results of the simulations were analysed further, aimed at establishing a simple approach to assess the wastewater system's RTC potential. More specifically, a regression relationship was established, relating the values of system properties of the given wastewater system to the reduction of time periods of critically low DO concentrations in the receiving river obtained by two types of RTC (base case static control and integrated hierarchical control). The regression coefficients are shown in Table 5.

A regression coefficient R^2 of approximately 0.9 was obtained, indicating a good correlation between the variation of the system characteristics and the established RTC potential. This is demonstrated in Fig. 6 where the RTC potential as established in the simulations is plotted against RTC potential as predicted using the regression. In such a plot, all points would lie on the $y=x$ line if the regression was perfect.

Based on that regression, an RTC Potential Calculator was developed, programmed in MATLAB®, shown in Fig. 7. This tool gives an estimation of the RTC potential after the user has provided information regarding the six most significant parameters (in terms of RTC) of the wastewater system under study. The RTC Potential Calculator operates under a graphical user interface (GUI) to facilitate its use, whereby users make use of slider bars to set the values of their system properties. Rather than using absolute numbers, the calculator makes use of descriptive values for the system properties, such as 'downstream', 'upstream', etc. The thinking behind this is that the calculator is not developed as a detailed simulation/prediction tool, rather a screening and decision-making tool. Therefore, the use of such descriptive parameters makes it user-friendly and much more relevant to its intended use. The user, however, is

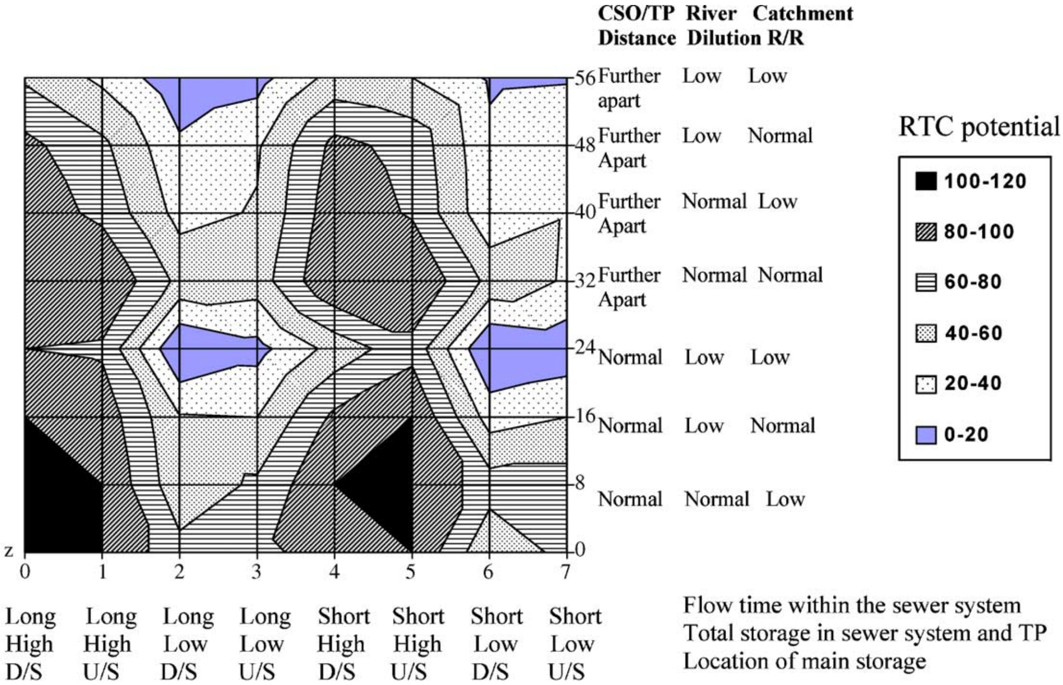

Fig. 5. RTC potential (DO) achieved by application of integrated control, adapted from Schutze et al. (2002b).

reminded of the range within which the regression holds and cannot choose parameter values outside that range. Potential is expressed as the reduction of critical river DO violation frequency and is classified in three categories (low, medium and high).

6.1. Incorporating critically low ammonia concentrations

Further work was carried out where the duration of critically high ammonia concentrations (the AMM-DU criterion) is used as the criterion for establishing RTC potential. This was performed in order to establish the effect on ammonia concentrations of optimising the system based on the DO-DU criterion.

It can be seen clearly from Figs. 8 and 9 that the response from ammonia concentrations is not as positive as that seen from DO concentrations. This is not necessarily surprising, since optimisation of the control strategy has been carried out with respect to DO, not to AMM, but nevertheless is important to quantify and understand. Although regions of high potential can be seen, these are not as large as in the results for DO shown in Fig. 5. Specifically, high potential is seen for low total storage volume (cf. the lightly shaded regions between the lines marked '2' and '3') as well as low

Table 4
Sensitivity of RTC potential to the system properties analysed

Most significant	Least significant
Total storage volume	River catchment rainfall–runoff factor
River base flow (dilution capacity)	Flow time within the sewer system
Location of CSO and treatment plant discharges	Storage distribution

Table 5
Regression coefficients

Coefficient	Value
Intercept	106.5935
Total storage volume	−13.2149
River base flow (dilution capacity)	−14.1649
Location of CSO and treatment plant discharges	−3.47742
River catchment rainfall–runoff factor	−2.03367
Flow time within the sewer system	−47.7024
Storage distribution	0.822593

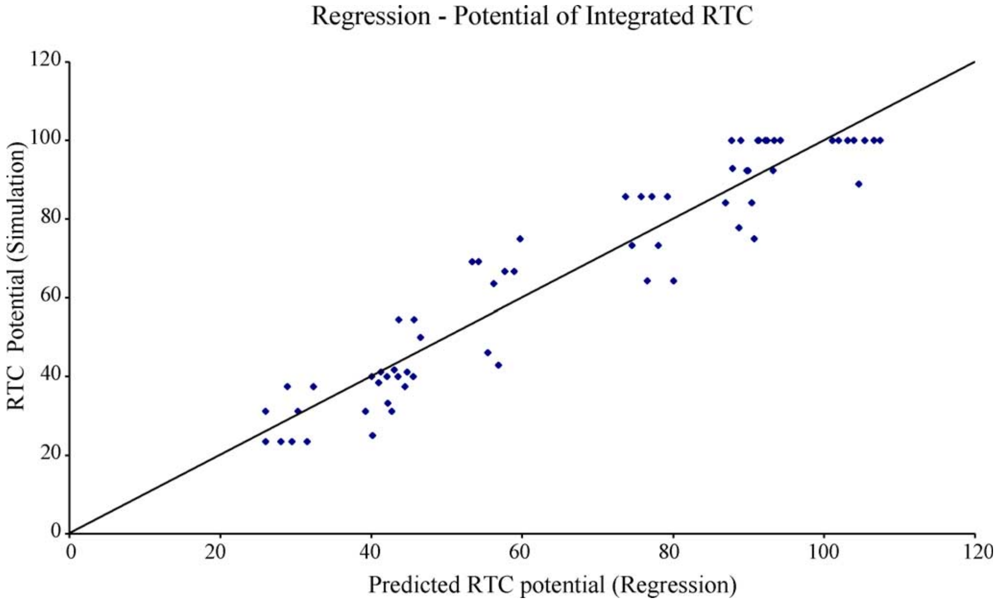

Fig. 6. Plot of predicted RTC against simulated RTC based on DO.

storage volume combined with a larger distance between the CSO and the treatment plant (cf. the lightly shaded region around the intersection of lines marked '6' and '32'). Large reduction in potential is seen in areas of low storage and normal river dilution (cf. the dark regions around the intersection of lines marked '6' and '40', '48' and '0' and '8').

Interestingly, the regions of high DO potential coincide with regions where ammonia potential is indicated as neither positive nor negative. Similarly, particularly high or low ammonia potential regions coincide with regions with average DO potential. This clearly indicates that optimising the system for DO potential does not necessarily improve the ammonia potential; in fact, the opposite effect is mostly commonly observed.

The reasons for the apparent increase in ammonia levels have not been firmly established. However, the most plausible explanation is that optimising the system based on the river DO criterion alters the operation of the wastewater treatment plant in a way leading to a reduction in nitrification capacity. Extensive work investigating the tracking of nitrogen through the urban wastewater system is currently underway, and this should shed light on the subtleties of this issue.

6.2. Widening the parameter space

The initial regression analysis was based on 64 scenarios, which resulted from using a base and a modified value for the six system parameters chosen. This was extended to 729 (3^6) variations,

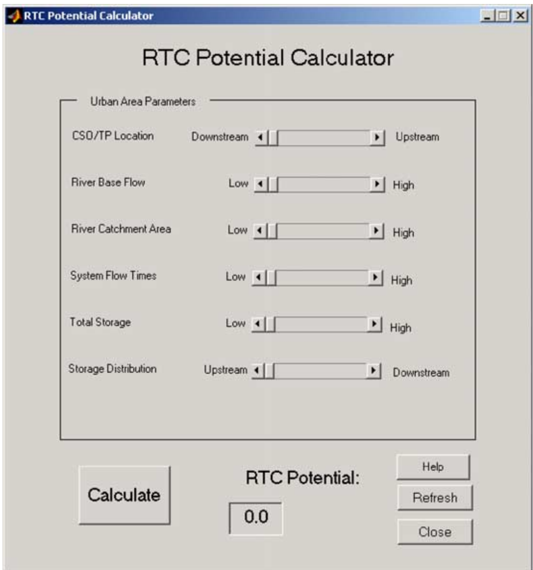

Fig. 7. RTC potential calculator.

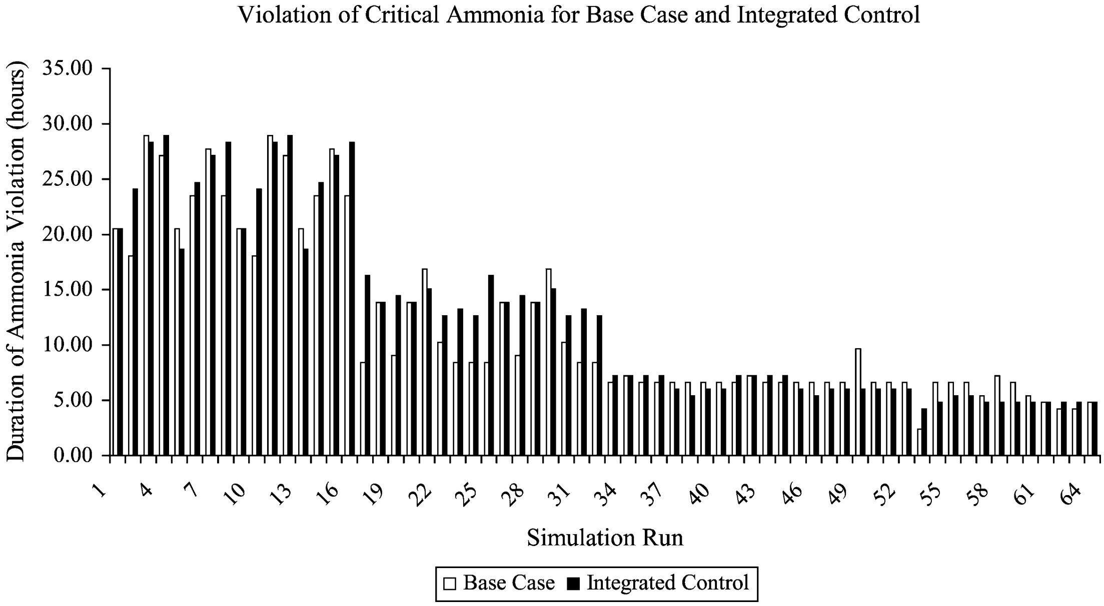

Fig. 8. Violation of critical ammonia for local and integrated control.

using a base value, a high and a low value. The objective of this was to increase the size of the parameter space upon which the RTC Potential Calculator was based. There was, however, concern that this large increase in the number of variations (for two values per system property: $2^6 = 64$; three: $3^6 = 729$; four: $4^6 = 4096$, etc.) would lead to weakening of the regression strength. The results are shown in Fig. 10, which is plotted in the same manner as Figs. 5 and 9.

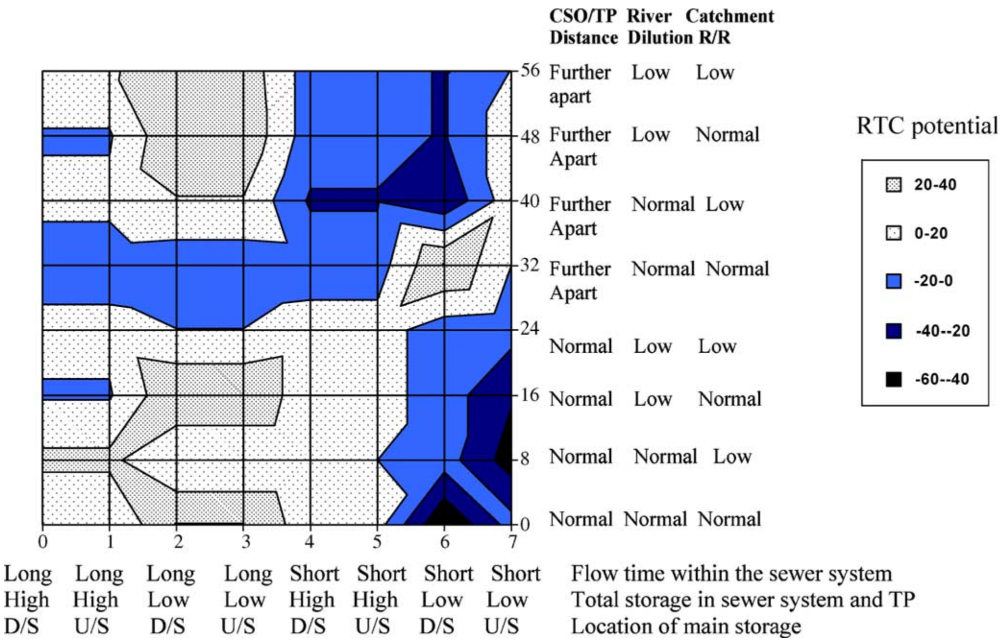

Fig. 9. RTC potential (AMM) achieved by application of integrated control.

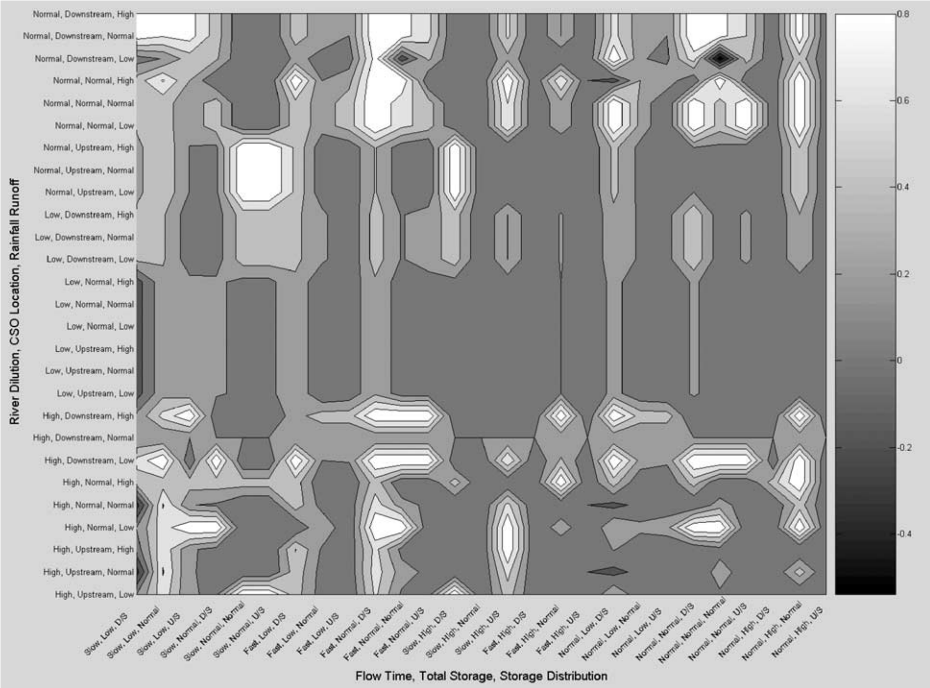

Fig. 10. Results from the 729 case study runs.

Indeed, it was found that the regression strength weakened significantly by making a large extension to the parameter space and it was deemed less useful in terms of the RTC Potential Calculator compared to the regression based on the 64 case study runs. However, the results shown in Fig. 10 have provided very important information regarding possible regions of high potential and on the combinations of parameters that may yield high potential.

Table 6
Application of the RTC Potential Calculator to real case study sites

Catchment	Total storage volume	Location of storage	Sewer flow times	CSO location	River base flow	River catchment area	Existing RTC?	RTC potential (as predicted)
Preston	H	U	L	U	H	H	N	Low
Blackburn	L	U	H	U	L	L	N	High
Oldham	H	U	H	U	L	H	Y	High
Bolton	H	U	L	U	L	L	Y	High
Carlisle	L	U	L	U	H	H	N	High
Blackpool	H	U	L	U	L	L	Y	High
Southport	L	U	L	U	L	L	N	High
Barrow	H	U	L	U	L	L	N	High
Morecambe	H	U	L	U	L	L	Y	High
Lancaster	H	U	L	U	H	H	N	Low
Chorley	L	U	L	U	L	L	N	High
Wigan	H	U	L	U	L	H	N	Medium
Hoylake	L	U	L	U	L	L	N	High

7. Application of the RTC screening tool to case study sites

Application of the methodology to case study sites was performed using data gathered from industrial collaborators and performed in close co-operation with them. The results, based on screening for the DO criterion, are shown in Table 6.

What the results reveal is that in areas where RTC is operational (which are relatively few), the RTC Potential Calculator did confirm the high RTC potential. High potential was also indicated for some catchments with no implemented RTC. Particularly high values were indicated for Blackburn, Southport, Chorley and Hoylake. Looking at the system characteristics of these catchments in more detail reveals that they share some common attributes with the sites with operational RTC.

In the sites with implemented RTC, river catchment areas, river base flow and sewer flow times were predominantly low, while total storage was always high. Sites with no RTC (but still high potential) had similar characteristics with the exception of total storage volume, generally, but not wholly, being low. This may seem odd, as total storage has been shown to have a strong impact on RTC potential. However, it is the *combination of parameters* that is important in establishing RTC potential. Therefore, the RTC Potential Calculator is suggesting that there is value in analysing the implementation of RTC in those catchments in further detail.

8. Conclusion

A methodology to establish the RTC potential using integrated modelling of the entire urban wastewater system has been developed based on the integrated simulation tool SYNOPSIS. SYNOPSIS was developed to assist studies of the urban wastewater system following the need for an integrated perspective and consists of three main simulation sub-programs for modelling water flow and quality processes in the urban drainage system, WWTP and river system. Using SYNOPSIS, a number of real-time control algorithms were developed and optimised, allowing for local, global and integrated scenarios to be considered. Analysis of the results revealed those system parameters which were of particular significance to the RTC potential of UWWS and provided the basis for the development of a screening procedure referred to as the RTC Potential Calculator.

The definition of the wastewater system's performance used in the RTC Potential Calculator focuses on minimising the duration of critically low concentrations of dissolved oxygen DO in the river (the so-called 'DO-DU' criterion). The analysis was conducted for a large number of case study sites, comprising sewer system, wastewater treatment plant and receiving waters of different layout. System variations were obtained by all possible combinations of two different values, a base and a modified value, of each of the six most significant parameters identified. For each of these, two paradigms of RTC were tested: the first relates to a scenario of optimised integrated control, while the other reflects an example of optimised local control. A good correlation between the variation of the system characteristics and the established RTC potential was obtained.

Further work is presented where the duration of critically low ammonia–nitrogen concentrations (the AMM-DU criterion) was used as the criterion for establishing RTC potential. Comparisons were made between the RTC potential based on DO-DU and the ensuing potential based on AMM-DU criteria. The results indicated that optimising the system for maintaining dissolved oxygen levels in the river may have a variable effect on ammonia concentrations. The reason why lower or indeed negative potential was observed is related to the operation of the system and probably the loss of nitrification in the activated sludge plant under certain conditions. If both DO and ammonia concentrations are to be minimised, multiple objectives must be taken into consideration and future developments must focus on a methodology that can incorporate these.

The findings from the theoretical simulation study have been complemented by an analysis of various wastewater systems currently under RTC and the application of the tool to real wastewater systems where RTC potential has been established. Whilst this is not formal validation of the model, it does increase confidence in its veracity. It is suggested that the *Calculator* is now a useful screening procedure to assist water companies, consultancies and regulatory agencies in assessing the potential of real-time control measures for sewer system, treatment plant and receiving water bodies.

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