Wastewater Planning for the Aire Catchment – assessment of effluent discharge controls to meet environmental objectives

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INTRODUCTION

River water quality planning in England and Wales is a key guardianship responsibility for the Environment Agency (referred to in this paper as the "Agency") in protecting and improving the quality of rivers. The Agency's river quality planning activities are aimed at achieving a balance between all the various demands by controlling effluent discharges and setting appropriate river quality targets to allow designated beneficial uses to be achieved. Water Companies, who are responsible for meeting environmental standards in the most financially efficient manner, also use water quality planning tools for this purpose, particularly when considering options for meeting standards.

As receiving and discharge water standards are often expressed in probability terms, then tools to support river water quality and planning also need to be probability based. This paper sets out to describe the key features of one such tool, to show its application to a series of rivers in the industrialised part of Yorkshire, and explores findings coming out of the modelling that link continuous and intermittent discharge performance.

SIMCAT

In the UK, river water quality modelling with the Agency's SIMCAT model (Environment Agency, 2002) is recognised as the best current approach to support decision making for river water quality management and planning. It offers a significant insight into catchment behaviour based on the use of existing routine monitoring of river and effluent quality for continuous discharges. It is designed to produce stochastic results with identified confidence levels for comparison against water quality standards and planning criteria.

SIMCAT has been widely used in the UK for over twenty years and is recognised as being a cost-effective, practical water quality management tool. Such models are routinely used to derive effluent discharge consent standards on a catchment scale to allow a range of national river quality standards and EC Directive water quality targets to be met. In particular, river catchment models are being used to examine the 'in combination' effects of multiple discharges and abstractions in reviewing consents that could impact on sites designated under the Habitats Directive. In the future, river quality planning models are likely to be a major component of the Agency's approach to river basin planning for implementation of the Water Framework Directive (EEC, 2000; EEC, 2004).

SIMCAT is a mathematical model that describes the quality of river water throughout a catchment by using a Monte-Carlo simulation approach to predict the behaviour of the summary statistics of flow and water quality, such as the mean and a range of percentiles. It is a one dimensional, steady state model that can represent inputs from both point-source discharges and diffuse inputs.

While this approach to water quality modelling may seem simple, the power of such modelling lies in the ability to derive quality relationships between points in a river based on the statistics of observed data. This enables it to consider errors associated with sampling of data rather than errors associated with calibration of more detailed deterministic water quality process representations. Hence, the advantages of speed, ease of use and maximised value from existing data. It also controls the effect of the statistical uncertainties associated with water quality data on decision making.

The advantages of the SIMCAT approach, with associated input data processing are:

- Proven software available from the Agency;
- Makes best use of existing available, but often limited data;
- Readily applied at a catchment scale;
- Used as a routine tool by trained non-specialist staff; and,
- Allows rapid assessment of management options.

THE AIRE AND CALDER CATCHMENT

To support regional and national water quality planning, including a major review of the sources and impacts of pollution loads entering the Humber Estuary for the Habitats Directive, the North East Region of the Environment Agency are developing a suite of strategic SIMCAT models. These will cover all the major river catchments in Yorkshire, two of the most important being the Aire and Calder catchments, which flow through West Yorkshire.

The combined catchment of the rivers Aire and Calder is shown in Figure 1. The River Aire flows east from Malham to its confluence with the Ouse near Goole and has a catchment area of 1100km^2. The Aire flows through the urban areas of Skipton, Keighley, Bradford and Leeds. The River Calder flows east from the Pennine Moors (near Todmorden) to the River Aire at Castleford and has a catchment area of 957km^2. The catchment is predominantly urban, and passes through Halifax, Brighouse, Huddersfield, Dewsbury and Wakefield.

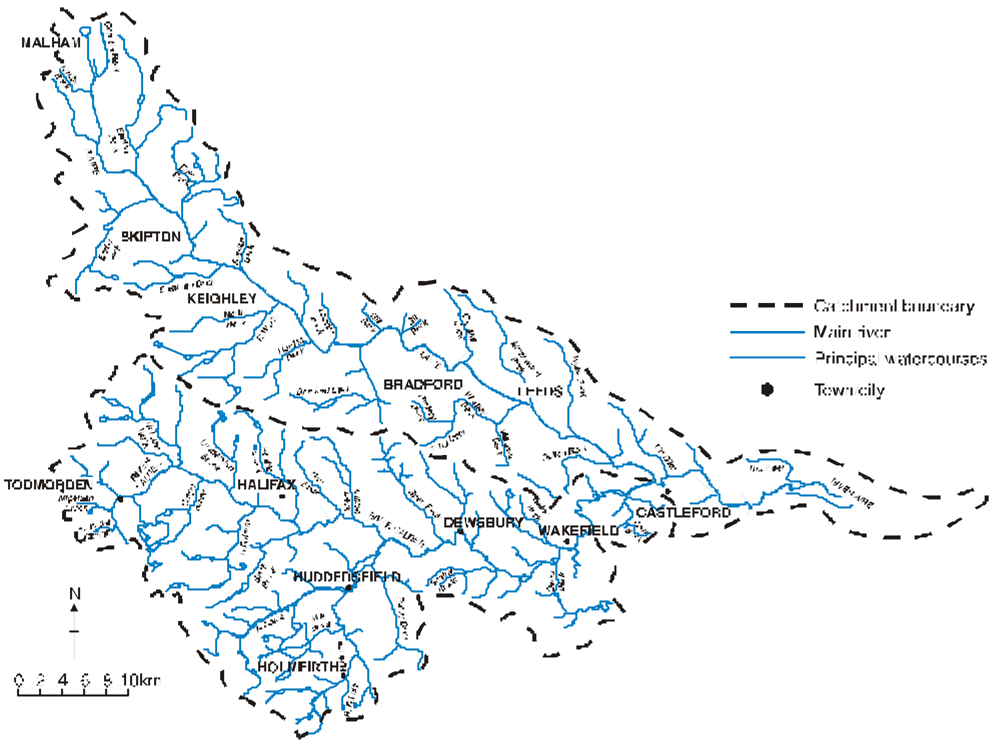

Figure 1 River Aire and River Calder catchment

The two catchments, with a population of over 1.9 million people, are important for public water supply, and water is transferred to the Aire catchment by Yorkshire Water Services from other rural catchments. The Calder catchment has 39 reservoirs in the headwaters for public water supply, where some water is brought in from adjacent catchments. There are also arrangements for flow augmentation of the Calder during droughts. The rivers are a source of water for industrial use and both rivers are important for recreation such as fishing, canoeing and navigation. Canals and canalised rivers, like the Leeds and Liverpool Canal, Rochdale Canal, and Aire and Calder Navigation are popular watercourses for recreational use.

The rivers in the catchment receive a large number of effluent discharges that need to be controlled to ensure compliance with the relevant national legislation, in terms of RE Class Objectives (DoE 1994) and EEC Directives, such as the Freshwater Fish Directive (FFD) (EEC 1978) and their associated river quality targets.

DEVELOPMENT OF SIMCAT MODELS

1. Reaches and Features – Model Conceptualisation

The models included all classified river reaches in the catchment. The number of features included in the model are summarised in Table 1. All Yorkshire Water (YW) STW effluents with a PE>250 were included. Table 2 gives a summary of the RE Class reaches and FFD stretches in the catchment.

Table 1 Catchment Features

Catchment	No. WQ Points*	No. Flow Gauges	No. Effluent Discharges**	No. Abstractions	Modelled Length (km)	No. SIMCAT Reaches
Aire	91	11	28 + 5	12	504.4	97
Calder	80	10	21	27	408.7	85
Total	**171**	**21**	**49 + 5**	**39**	**913.1**	**182**

* routine water quality monitoring sites
** (YW + industrial)

Table 2 Summary of River Quality Objectives

	RE Class					FFD	
Catchment	1	2	3	4	5	Salmonid	Cyprinid
Aire	6	37	20	27	1	31	19
Calder	4	34	11	21	0	23	17
Total	**10**	**71**	**31**	**48**	**1**	**54**	**36**

For ease of subsequent use, three individual SIMCAT models were produced for the following determinands:

- Flow, BOD, Ammonia, DO
- Flow, Phosphate, TON
- Flow, Diazinon, MCPA

The two 'Dangerous Substances', Diazinon and MCPA, are an important water quality consideration in these catchments and need to be controlled under the Dangerous Substances Directive (EEC 1976).

2. Data Analysis – SIMCAT input data

To give a key benefit in terms of subsequent model reliability, a robust statistical approach to data analysis for SIMCAT input data is applied. A detailed data analysis was carried out on all routine river and effluent flow and quality data for the catchment for the period 1998-2003. This included the identification and removal of outliers and step changes in the river and effluent flow and quality as illustrated in Figure 2. Input parameter statistical distributions were generated to characterise river and effluent flow and quality and correlation coefficients between river and effluent flow and quality parameters.

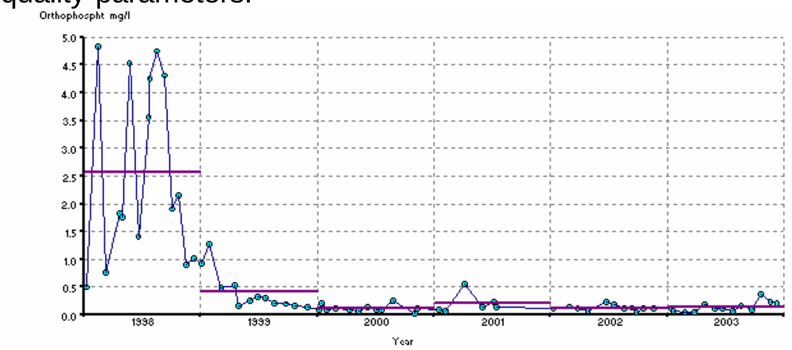

Figure 2 Step change in Phosphate at Spen Valley STW

3. Model Calibration

Calibration of a SIMCAT model is based on the manual calibration of flows, followed by pollutants, to meet an Agency target manual calibration criteria for model predictions of the mean and 95%ile to within ± the Standard Deviation (SD) of the observed flow and quality data statistics at that location. Manual calibration is achieved by adding diffuse inputs on a reach by reach basis to account for unmodelled inputs, such as small tributaries, and diffuse flows. Diffuse quality inputs and decay rates are estimated from observed data.

Observed data statistics may be re-assessed where calibration criteria cannot be met; for example, due to high variability in input data. SIMCAT modelling includes a final autocalibration step to account for uncertainties in the input data, such as sampling error and any unknown inputs (Environment Agency 2002). The autocalibration adjustments, in terms of the load added or removed from a reach to match the observed data, are preserved and applied in any scenario assessment.

Generally, manual calibration on the Aire and Calder SIMCAT model achieved a good match between predicted and observed quality for all determinands, with the predicted mean values mostly within the criteria of ± 1 SD of the observed value. The fit to the 95%ile values was not as good as that achieved for the mean values due to the variable nature of the data that typically results from periodic high values, low sampling frequency and limit of detection issues. As an illustrative example, Figure 3 shows the final manual calibration for mean BOD before auto-calibration. Figure 4 shows the final manual calibration for the River Aire for BOD, Ammonia and DO.

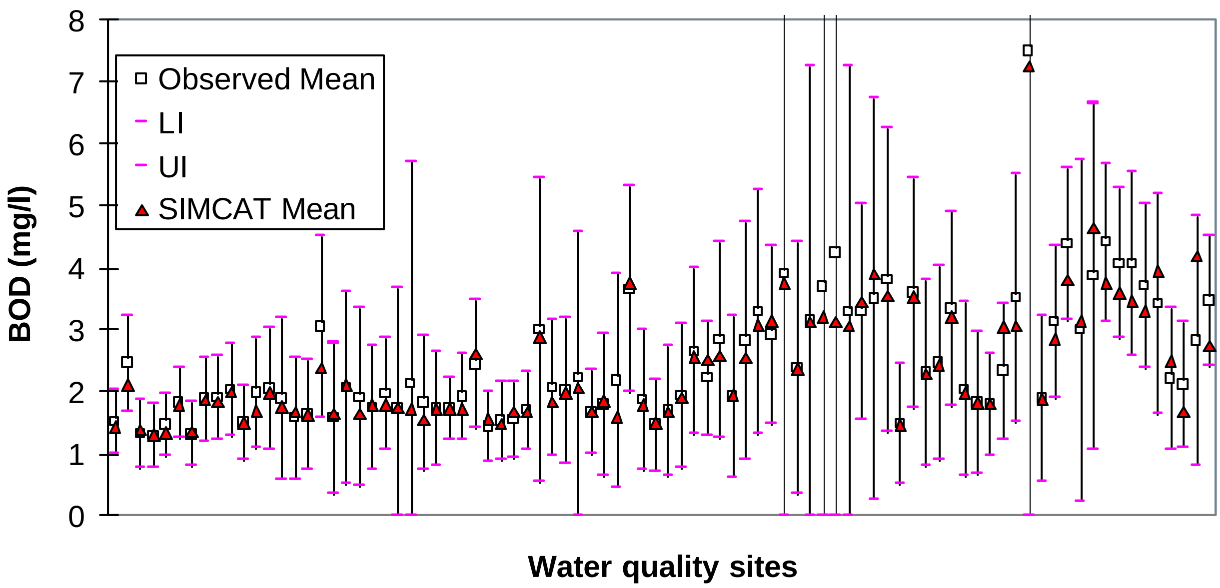

Figure 3 Manual calibration results for BOD

In a number of cases where the calibration criteria cannot be met there is a clear mismatch between the modelled input for an effluent discharge and the observed impact immediately downstream. These mismatches are likely to be due to uncertainty in the effluent flow and quality data.

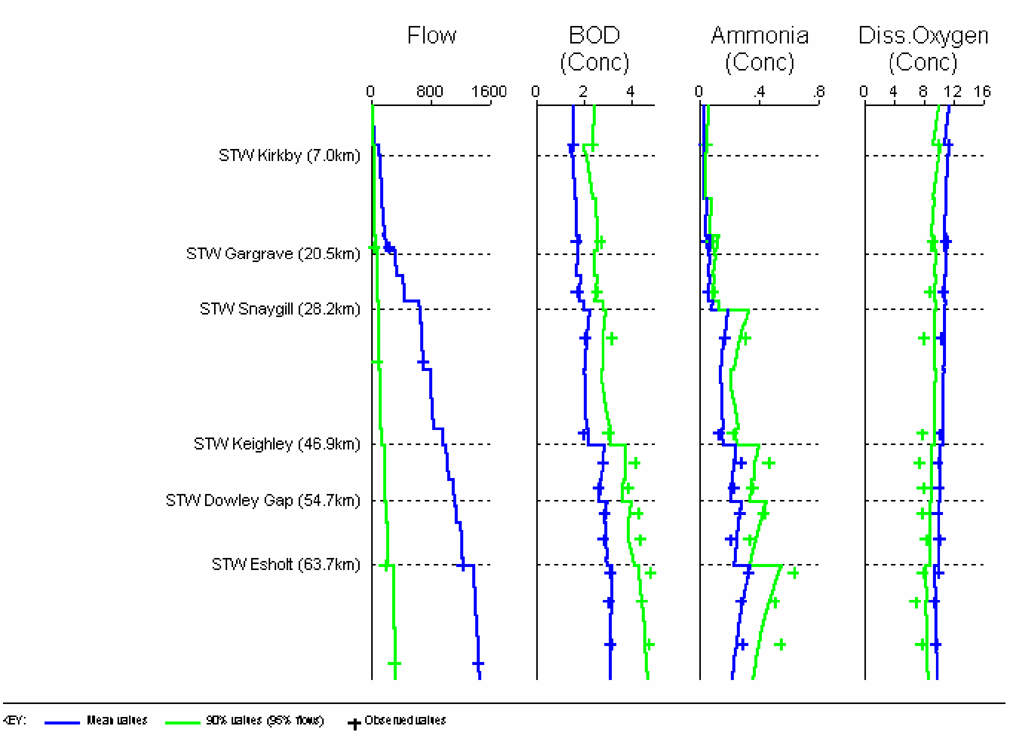

Figure 4 River Aire Manual Calibration for Flow, BOD, Ammonia and DO

4. Pollution Load Analysis

Table 3 presents the average diffuse loads added to the modelled reaches during manual calibration. The use of higher diffuse inputs to the rivers in the urban areas indicates that urban non-point sources of pollution are impacting on these rivers. These sources could be intermittent wet weather discharges from storm tanks, CSOs, urban and highway runoff.

Table 3 Average manual calibration diffuse pollution load input rates (kg/day/km)

Source	BOD	Ammonia	Phosphate	TON
Urban diffuse (kg/d/km)*	84	20	<1	21
Non-urban diffuse (kg/d/km)**	15	2	<1	8

*Urban = 160.7km, **non-urban = 752.4km

For the model as a whole, *diffuse* sources of load are more significant than effluent discharges for BOD and Ammonia. Effluent discharges are the most significant source of Phosphate, TON, Diazinon and MCPA loads. Figure 5 presents the relative sources of load for Ammonia and Phosphate.

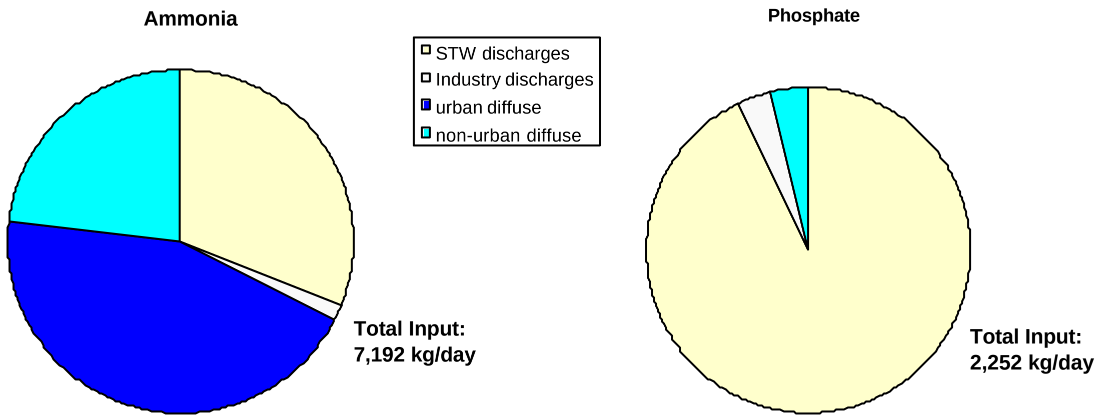

Figure 5 Relative Load Sources for Ammonia and Phosphate

INVESTIGATION OF WET WEATHER IMPACTS

Further data analysis was carried out on a limited number of STW discharge and river quality data sets to identify if data collected following rainfall differed from data collected under dry weather conditions. The analysis was applied to 10 years of data from 7 STWs, 10 river quality sites and 5 daily recording rain gauges in the catchment. The sites selected were representative of urban and non-urban areas of the catchment.

A WRc statistical programme called WADI (Wet Against Dry Investigation) was used to investigate any difference in mean quality on wet and dry days. Based on experience from a range of catchments, wet weather days were defined as days when greater than or equal to 2 mm of rain had fallen on *that* day *or* 3 mm the day before. WADI then separates wet weather 'samples' from dry weather 'samples' and tests for a statistically significant difference in the average concentration for each determinand.

The WADI results, where significant differences were found, are presented in Table 4 and can be summarised as:

- Most urban river sites have higher BOD concentrations under wet conditions.
- Both non urban and urban river sites have lower Ammonia concentrations under wet conditions.
- Both non urban and urban river sites show little impact of wet weather on DO.
- In general, STWs showed a variable response to wet weather for BOD and lower concentrations for Ammonia in wet weather.

The WADI results tend to confirm that wet weather impacts can be related to wet weather urban diffuse pollution rather than the continuous STW discharges.

Table 4 WADI results for BOD and Ammonia

Site Code	Site Name	BOD		Ammonia	
		Wet mean (mg/l)	Dry mean (mg/l)	Wet mean (mg/l)	Dry mean (mg/l)
49400927	Keighley STW	12.7	14.5	1.1	1.5
49400659	Esholt STW	7.3	6.5	0.8	1.0
49400883	Knostrop STW	NS	NS	2.9	3.7
49500740	Cooper Bridge (Huddersfield) STW	10.9	12.2	3.8	4.4
49505039	Colne Bridge (Huddersfield) STW	*NS*	*NS*	1.8	2.4
49505059	Spen Valley STW	*NS*	*NS*	1.8	2.3
49400723	River Aire at East Riddlesden Hall	2.6	2.0	*NS*	*NS*
49400676	River Aire at Apperley Bridge	5.4	4.0	*NS*	*NS*
49400426	River Aire at Kirkstall Bridge	5.0	3.2	*NS*	*NS*
49400424	River Aire at Fleet Weir	*NS*	*NS*	0.6	1.0
49500602	River Calder at Copley Church	2.8	2.2	*NS*	*NS*
49500621	River Calder at North Dene Bridge	4.3	3.6	0.8	1.2
49500619	River Calder at Mitchell Cotts Bridge	6.1	4.4	0.9	1.2
49500607	River Calder at Dewsbury	5.3	4.4	*NS*	*NS*

NS: Not significant

MODELLING SCENARIOS

The SIMCAT models were used to investigate four what-if modelling scenarios:

Scenario 1: Current actual performance

What is the predicted river quality when all effluent discharges operate at their current observed performance for flow and quality?

Scenario 2: Current consented quality (AMP3)

How does the predicted river quality change when the AMP3 consents are implemented?

Scenario 3: Future planned quality (AMP4)
How does the predicted river quality change when the future planned AMP4 upgrades are implemented?

Scenario 4: Future revised quality
What is the STW effluent discharge quality required to meet the downstream water quality targets?

STW performance was altered to represent the discharge performance specified for each scenario, except for scenario 4, where SIMCAT was used to identify future revised consents to achieve all specified river quality targets – RE, FFD, dangerous substances and a notional future river Phosphate target of an annual mean of 0.06mg/l.

For scenario 4, the Agency specified the tightest consents to be used as:

- BOD 95%ile 10 mg/l;
- Ammonia 95%ile 3 mg/l; and,
- Phosphate mean 1mg/l.

Table 5 summarises the results of the modelling scenarios in terms of the percent of designated reaches failing all the specified targets for each RQO or EQS. For most criteria, the current actual performance is better than the future planned performance when all discharges are operating at their consent limits.

Table 5 Scenario results: % of designated reaches failing water quality target

	RE Class	FFD	Phosphate	Diazinon	MCPA
Current Actual	25	36	69	28	0
Current Consented	28	43	69	38	0
Future Planned	26	40	68	41	0
Future Revised	23	29	66	34	0

Revised consents were calculated for 18 STWs to achieve RE and FFD targets in Scenario 4. The remaining failures were due to a combination of poor upstream quality and application of the tightest consents specified. Significant exceedances of the Phosphate target remained after application of the maximum Phosphate removal consent at 95% of the STWs in the catchment. Table 6 illustrates the pollution loads discharged from the catchment under each scenario.

Table 6 Scenario results: predicted load at end of catchment

	BOD (kg/d)	Ammonia (kg/d)	Phosphate (kg/d)	TON (kg/d)	Diazinon (g/d)	MCPA (kg/d)
Current Actual	9727	1550	1848	17015	130.6	1.8
Current Consented	10959	1755	2124	17930	147.6	2.0
Future Planned	10475	1583	2122	17927	147.6	2.0
Future Revised	10058	1580	912	17927	56.4	1.7

This information is both of use now, and in the future. For example, by understanding where improvements to water quality are most (or least) likely to be required in the future, then decisions on whether to meet tighter consent limits by either upgrading processes, or adding tertiary plant can sensibly be made.

In addition, where it is identified that proposed tighter limits cannot be met by current levels of treatment, then this can by highlighted at an early stage, to allow debates on standards, sources of pollution, and level and cost of treatment, to be had between interested parties.

CONCLUSIONS

The three SIMCAT models developed for the Aire catchment were successfully calibrated and applied to a number of future water quality planning scenarios and are available for use as strategic catchment planning tools. The results indicate that there are a number of locations in the catchment where further investigations are required to improve current understanding of the nature and causes of water quality problems.

A key outcome of the study is the identification of a significant mismatch between inputs from continuous discharges and the observed deterioration in river quality in the urbanised valleys of the upper Calder and middle Aire. Intermittent, wet weather, urban pollution from CSOs, Storm tanks and other diffuse urban inputs are believed to be major factors in this mismatch. Wastewater planning scenarios, with STW consents set at the current limits specified under Agency policy, indicate that future river quality standards will be at risk unless these intermittent sources are also understood and controlled.

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ACKNOWLEDGEMENT

This paper has been produced with the permission of the Directors of the Environment Agency, WRc plc and Yorkshire Water. The views expressed in the paper are those of the authors and not necessarily the views of these organisations.