Analysis of Structural Uncertainty in the Analytical Solution of ADE in River Impacted By CSOs

V.Camacho[1*], T. Norris[1,2], J. D Shucksmith[1]

[1]University of Sheffield, Department of Civil and Structural Engineering, Sir Frederick Mappin Building, Sheffield, UK (*Corresponding author's email: v.camacho@sheffield.ac.uk)
[2]United Utilities, Lingley Mere Business Park, Warrington, UK

Abstract
Analytical and numerical models can be used to represent the advection-dispersion processes governing the transport of pollutants in rivers (Fan et al., 2015; Van Genuchten et al., 2013). Simplifications and assumptions in these models result in various uncertainties within the modelling process and estimations of pollutant concentrations. One example of a common simplification is the assumption that when a pollutant is released into a river location (for example from a CSO discharge), the pollutant is instantaneously fully mixed over the river cross section (Kannel et al., 2011; Sharma et al., 2013). Although models may allow a certain advection length for transverse mixing processes to occur, this length is usually estimated based on empirical data. The scale and significance of these uncertainties has not previously been examined. This study aims to analyse the relative structural uncertainty of different analytical solutions of the ADE when simulating BOD concentrations downstream of a CSO discharge. Model boundary conditions, input datasets and river quality datasets are based on an integrated model verification study conducted within an urban catchment in the UK.

Keywords
Advection dispersion equation, CSO discharge, pollutant transport

INTRODUCTION

A study case (Figure 1) is presented from an urban catchment in the United Kingdom where a CSO discharge occurs during wet weather conditions. Flow and quality data describing the CSO spill has been collected as part of a wider integrated model verification study (Norris et al., 2014). Within the integrated model, the receiving water is modelled using the DUFLOW package. Data from the model is extracted to provide boundary river conditions immediately upstream of the CSO, as well as the receiving water characteristics during the monitored spill event (**Error! Reference source not found.**).

Table 1. River and pollutant information

Parameter	Value
River velocity (ms^{-1})	1.0
Pollutant mass (kg)	1.0
River average depth (m)	2.5
River cross section area (m^2)	50
Longitudinal dispersion (m^2s^{-1})	0.2
Transverse dispersion (m^2s^{-1})	0.002

.

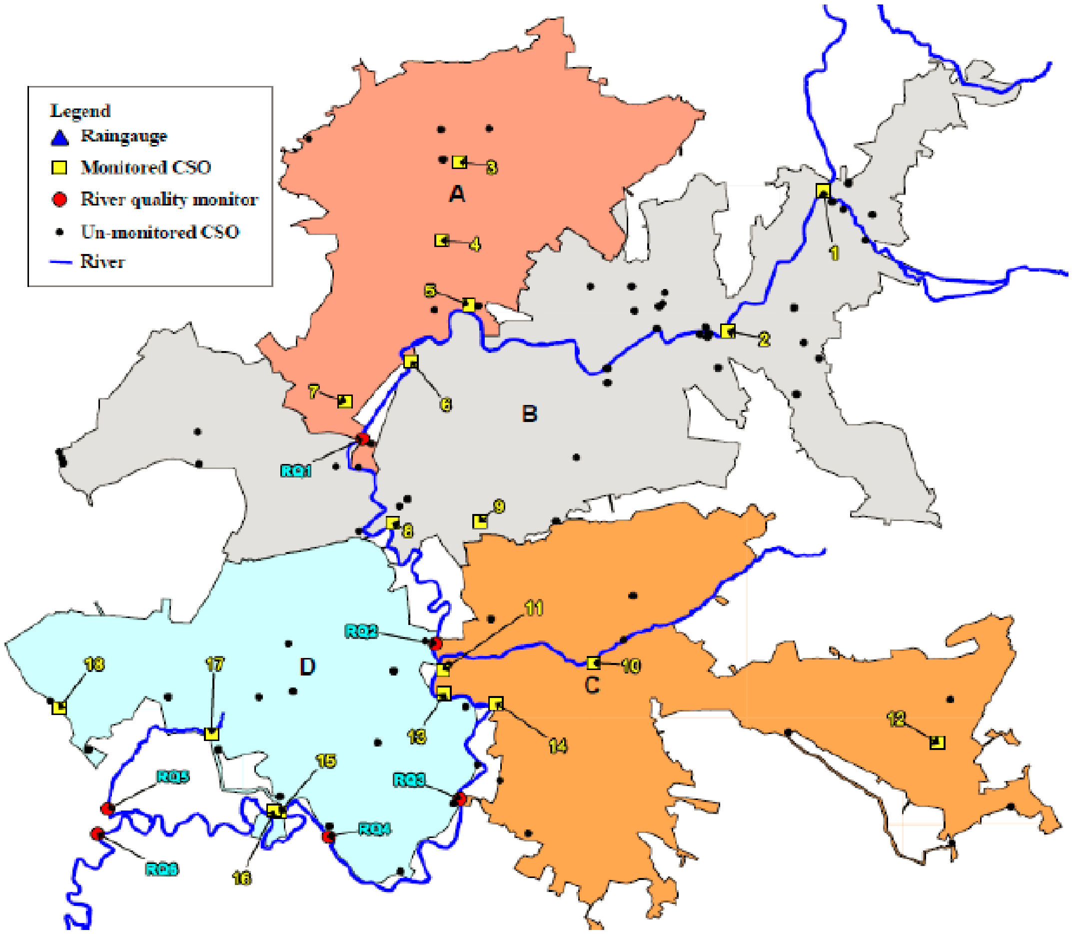

Figure 1. Study catchment (courtesy of Thomas Norris from United Utilities)

PRELIMINARY RESULTS

Depth averaged BOD concentrations at a selection of temporal and spatial (t,x) points after pollutant release from the modelling approaches are presented Figure 2. When comparing cases 3a and 3b to case 1 and case 2 (one dimensional cases), a large difference in concentrations is observed reaching several orders in magnitude. As the pollutant travels in the longitudinal direction, the pollutant mixes completely along the cross section, and the difference between the predictions reduces. However, for this scenario, it takes several kilometres to reach a completely mixed cross section.

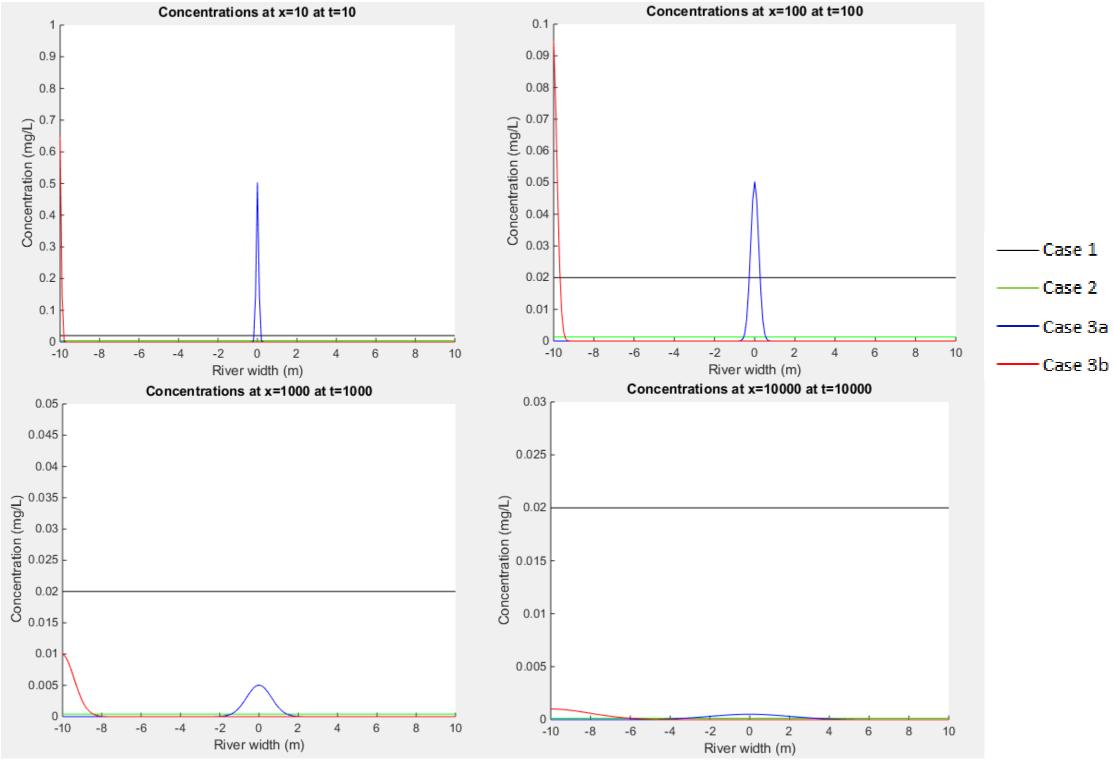

Figure 2. Modelled river BOD concentration profile in (mg/L) after CSO discharge at various times and distances after release. Black line shows advection processes only (1), green: advection-dispersion in a fully mixed cross section in the longitudinal direction (2), blue: advection-dispersion from a CSO discharge at the centre of the stream with longitudinal and transverse dispersion (3a), and advection-dispersion from a release at the river bank with longitudinal and transverse dispersion (3b).

Figure 3 shows estimated peak concentrations against distance for the four studied cases. It is observed that by considering only advection processes, the initial concentrations are underestimated while at longer distances, concentrations are overestimated. Similarly, when considering advection and only longitudinal dispersion, concentrations can be underestimated as shown for this particular study. Thus, Figure 2 illustrates the importance of identifying how the inherited structural uncertainty in the ADE may lead to equivocated estimations of pollutant loadings in river systems.

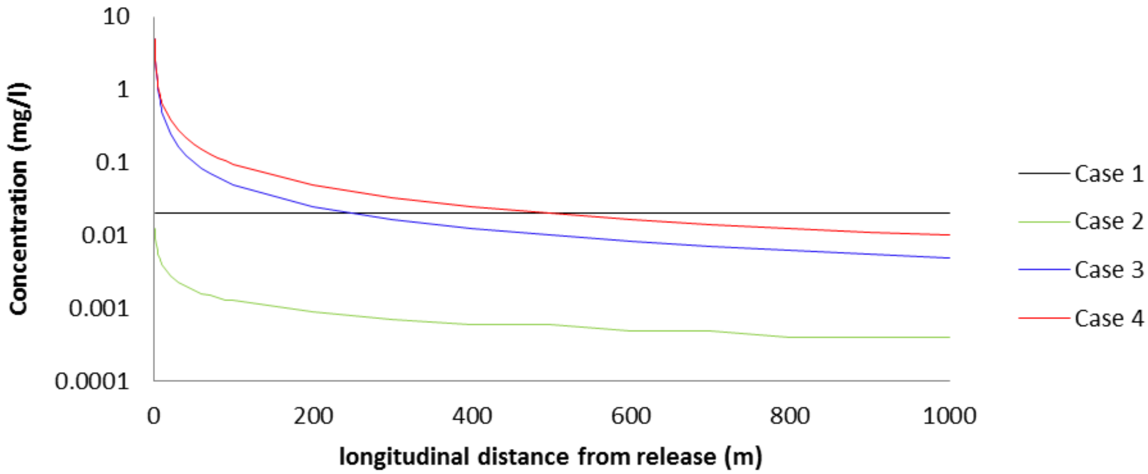

Figure 3. BOD peak concentrations in (mg/L) for the four cases vs. distance in (m) from CSO release

Similarly, uncertainties due the river hydraulics can be assessed for the various cases described above. Figure 4 shows the pollutant concentrations when the river velocity is increased and decreased by fifty percent. As observed, the estimated pollutant concentrations for the different cases still show large differences depending on the discretization of time and space. Future work will incorporate a more sophisticated river hydraulics model to asses and compare uncertainties from hydraulics whitin the various pollutant transport models.

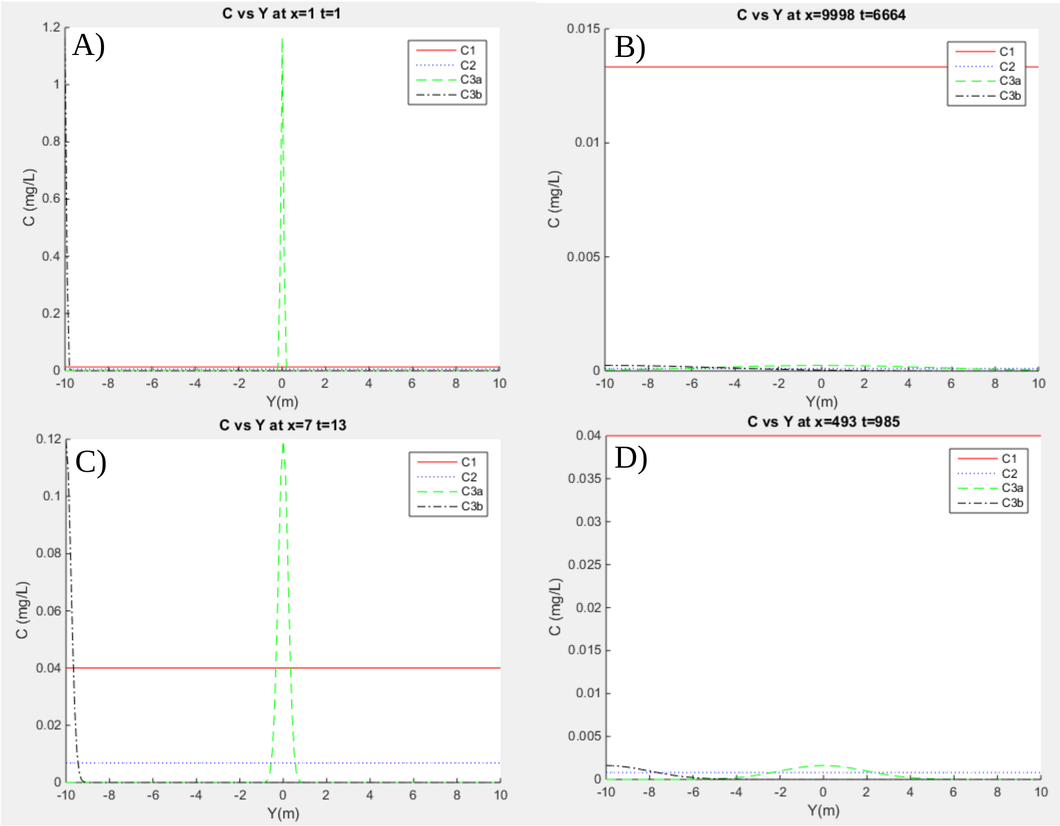

Figure 4. Modelled river concentrations using various velocities: A) and B) Vx = 1.5 ms^{-1}; C) and D) Vx = 0.5 ms^{-1}

FUTURE WORK

Initially, the pollutant is treated as an instantaneous release with a constant velocity. Future work will treat the CSO discharge as a time series discharge, and compare the analytical solutions to the DUFLOW model as well as monitored river quality datasets (from the verification study). The work presented in this abstract will be extended to include a decay coefficient for BOD concentrations, a input of CSO discharge as a time series, a varying river velocity due to wet weather conditions, a solution of the ADE accounting for the advective zone, and a comparison with a commercial model and river quality verification data.

ACKNOWLEDGEMENTS

The authors would like to thank United Utilities for sharing the data used for this study. This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 607000.

REFERENCES

Fan, F. M., Fleischmann, A. S., et al. (2015). Large-scale analytical water quality model coupled with GIS for simulation of point sourced pollutant discharges. Environmental Modelling and Software, 64, 58-71. doi: 10.1016/j.envsoft.2014.11.012

Kannel, P. R., Kanel, S. R., et al. (2011). A Review of Public Domain Water Quality Models for Simulating Dissolved Oxygen in Rivers and Streams. Environmental Modeling and Assessment, 16(2), 183-204. doi: 10.1007/s10666-010-9235-1

Mazijk, A. V. (1996). One dimensional approach of transport phenomena of dissolved matter in rivers (Doctorate), TU Delft, Delft.

Norris, T., Squibbs, G., et al. (2014). Evaluating the Use of Sewer Network Event Mean Concentrations within Integrated Catchment Models. Paper presented at the 13th International Conference on Urban Drainage, Sarawak, Malaysia,.

Sharma, D., & Kansal, A. (2013). Assessment of river quality models: A review. Reviews in Environmental Science and Biotechnology, 12(3), 285-311. doi: 10.1007/s11157-012-9285-8

Van Genuchten, M. T., Leij, F. J., et al. (2013). Exact analytical solutions for contaminant transport in rivers 1. The equilibrium advection-dispersion equation. Journal of Hydrology and Hydromechanics, 61(2), 146-160. doi: 10.2478/johh-2013-0020