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A risk-based approach to wastewater treatment plant cost-effective permitting

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Summary of key findings

A cost-effective effluent permitting approach is proposed in this study to maximize wastewater treatment plant (WWTP) performance in an energy and environmentally efficient manner. By incorporating cost and risk analysis into the traditional assessment of surface water quality standard compliance, more sustainable solutions can be developed by exploring trade-off relationships between different objectives to achieve balanced benefits.

Introduction

Permitting has been widely practiced as an effective approach to regulating discharges from wastewater treatment plants (WWTPs) to protect surface water bodies. In England and Wales, permits include pollutant concentration and flow rate limits expressed in statistical terms (e.g. 95%ile, 99%ile) (Environment Agency, 2011). Statistically-based permit calculation models, such as River Quality Planning (RQP), are efficient in yielding permit values to meet water quality targets of the receiving water body. However, some key aspects, such as cost and environmental risk, are not fully considered in permit setting. The aim of this paper is to propose an approach for setting cost-effective permits by incorporating cost-risk analysis. Benefits of the proposed approach are demonstrated by a case study.

Methodology

In the permitting tool RQP (Murdoch, 2012), effluent discharge (both flow rate and water quality) from WWTPs, as well as upstream river flow rate and water quality, are represented as random variables, described by probability distributions (typically lognormal) yielded from historical monitoring data. Monte-Carlo simulation is employed to draw values from the distributions and yield downstream river water quality values by solving a mass balance equation. After simulating a sufficient number of events, the percentile value for downstream water quality can be estimated from the results obtained. The water quality probability distribution of the WWTP effluent discharge is modified if the 90%ile (or 99%ile) water quality target in the downstream river reach is violated. The permit for WWTP effluent discharge is set according to the modified distribution.

An innovative framework is proposed in this study for integrated cost and risk analysis based on the RQP model. A consequence function is introduced to measure the impact of river water quality deterioration (Botto et al., 2014) as the exceedance of a standard limit. Environmental risk is calculated according to the widely used definition as the product of consequence (illustrated as dashed line in Figure 1a)) and probability (Liu et al., 2011) (solid line in Figure 1a), which is yielded from RQP). One set of consequence and probability functions, corresponding to one effluent water quality distribution, results in one risk value. Risk can be calculated with the modification of WWTP effluent quality distributions in permitting and plotted into a risk function against effluent 95%ile values as shown in Figure 1b). The cost associated with various levels of risk is produced by linking WWTP effluent 95%ile values with cost. This can be developed from monitoring data from WWTPs. However, due to lack of sufficient data, this paper uses a WWTP model instead to yield the cost function as illustrated in Figure 1b). Details on the definition of risk and cost are described as follows.

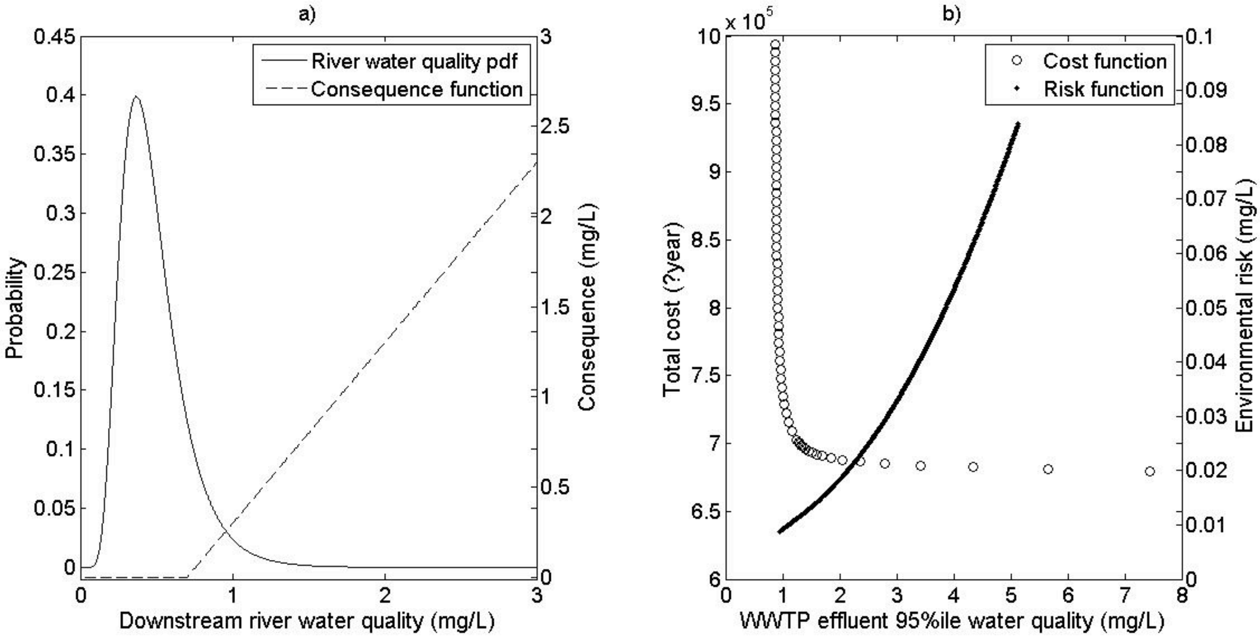

Figure 1 a) River water quality probability density function and consequence function for production of environmental risk; b) Construction of cost and risk functions

a. Definition of environmental risk:

As presented in Equations (1) and (2), expected environmental risk is defined as the integral of the product of consequence and related probability.

$$E = \begin{cases} 0 & (C < C_T) \\ C - C_T & (C \geq C_T) \end{cases} \tag{1}$$

$$\text{Risk} = \int_0^{\infty} E \cdot P dC \tag{2}$$

Where C is the downstream river water quality, C_T is the river water quality standard (e.g. 90%ile river water quality standard limit), E is the consequence corresponding to river water quality C, which is ($C - C_T$) if the river water quality is above C_T and is zero otherwise, and P is the related probability.

b. Definition of cost:

For completeness, both capital and operational cost should be considered in permitting. For simplicity, however, this paper investigates only operational costs assuming no change in capital cost, i.e. no upgrade in treatment process for compliance. The urban wastewater system modelling software platform SIMBA6 (IFAK, 2009) is used for WWTP modelling to calculate the operational cost entailed in pumping, aeration and sludge treatment.

Results and discussion

The proposed method is applied to a case study site, which consists of a semi-hypothetical nitrifying WWTP (Schutze et al., 2002) and a river in the English Midlands. In the baseline WWTP control scenario ('B1' in Figure 2), 90%ile downstream river total ammonia concentration violates the standard limit (Defra, 2010) based on a one-year simulation in SIMBA6. Thus the one-year simulation data on WWTP effluent discharge and upstream river flow are used as input data for risk and permit calculation by RQP ('Risk (base)' in Figure 2). The cost function is constructed using the WWTP model by varying aeration rate in the activated sludge tank while keeping other operational settings fixed. Annual operational cost and corresponding effluent 95%ile values of each operational strategy are summarized into the cost function ('Cost (base)' in Figure 2). To comply with the river water quality standard, effluent 95%ile total ammonia concentration (i.e. the effluent permit) need to be 2.10 NH3-N mg/L ('B2' in Figure 2) or lower (shown in cyan in 'Risk (base)' curve). However, the cost function indicates that it is technically and economically infeasible to achieve this by enlarging aeration capacity only.

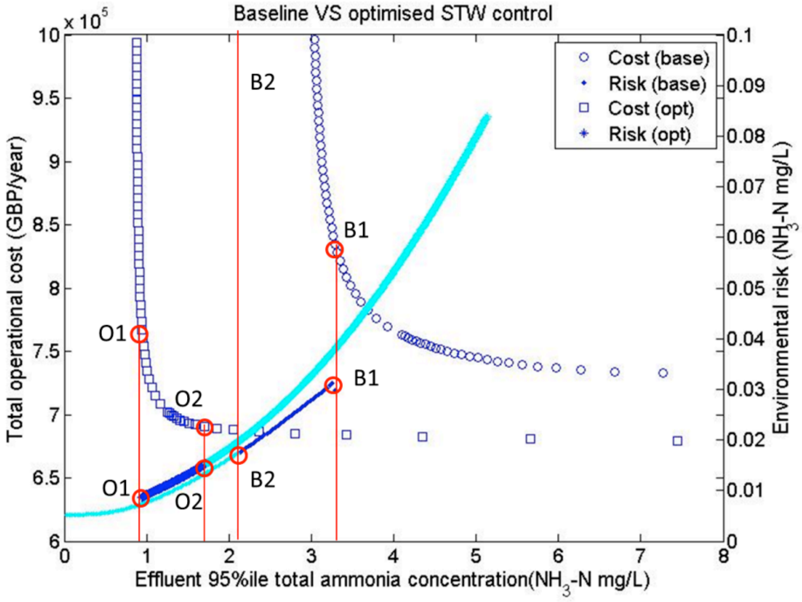

Figure 2 Cost and risk functions of two WWTP operational schemes of different sludge pumping rates (baseline and optimised)

In comparison, another operational control scenario ('O1' in Figure 2) is set up by changing return sludge pumping rate and waste sludge pumping rate while keeping other operational settings the same as scenario 'B1'. Results show that the water quality standard is satisfied with improved WWTP operations and the environmental risk is much lower than scenario 'B1' with 8% lower operational cost. Furthermore, the aeration rate can be decreased to a level as in scenario 'O2' while still meeting the standard (standard compliance operational solutions are shown in blue in the 'Risk (opt)' curve). The more relaxed effluent permit could save 9% in operational costs compared to scenario 'O1'. Any effluent 95%ile value between that of scenario 'O1' and 'O2' can be potentially set as the permit, depending on cost-risk trade-off analysis by the decision makers. Although the permit based on improved operational strategy ('O1' to 'O2') is more stringent than that of scenario 'B2', it is technically achievable with much lower operational cost. Thus desirable environmental outcomes can be achieved in a more cost-effective manner by incorporating cost-risk analysis of compliance strategies into permitting.

Conclusion

The integrated cost-risk analysis is demonstrated to be a valuable tool in evaluating technical feasibility, economic efficiency and environmental impact of different compliance strategies. The trade-off analysis between different objectives facilitates the derivation of cost-effective effluent permitting. Although the stochastic model RQP was used in this study to demonstrate the proposed approach, it is suggested that the method can be generalized to other types of permitting tools.

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References

Botto, A., Ganora, D., Laio, F. and Claps, P. (2014) Uncertainty compliant design flood estimation. *Water Resources Research,* 50, 4242–4253.

Defra (2010) The river basin districts typology , standards and groundwater threshold values (Water Framework Directive) (England and Wales) directions 2010.

Environment Agency (2011) How to comply with your environmental permit. Additional guidance for: water discharge and groundwater (from point source) activity permits (EPR 7.01).

IFAK (2009) SIMBA 6.0: simulation of wastewater systems. User's guide.

Liu, W., Moran, C.J. and Vink, S. (2011) Quantitative risk-based approach for improving water quality management in mining. *Environmental Scient &Technology*, 45, 7459–7464.

Murdoch, N. (2012) Introduction to river quality planning setting permits and assessing compliance.

Schutze, M., Butler, D. and Beck, B. (2002) *Modelling, simulation and control of urban wastewater systems*. Springer, London, UK.