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Research article

Developing a multi-pollutant conceptual framework for the selection and targeting of interventions in water industry catchment management schemes

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A B S T R A C T

In recent years water companies have started to adopt catchment management to reduce diffuse pollution in drinking water supply areas. The heterogeneity of catchments and the range of pollutants that must be removed to meet the EU Drinking Water Directive (98/83/EC) limits make it difficult to prioritise areas of a catchment for intervention. Thus conceptual frameworks are required that can disaggregate the components of pollutant risk and help water companies make decisions about where to target interventions in their catchments to maximum effect. This paper demonstrates the concept of generalising pollutants in the same framework by reviewing key pollutant processes within a source-mobilisation-delivery context. From this, criteria are developed (with input from water industry professionals involved in catchment management) which highlights the need for a new water industry specific conceptual framework. The new CaRPoW (Catchment Risk to Potable Water) framework uses the Source-Mobilisation-Delivery concept as modular components of risk that work at two scales, source and mobilisation at the field scale and delivery at the catchment scale. Disaggregating pollutant processes permits the main components of risk to be ascertained so that appropriate interventions can be selected. The generic structure also allows for the outputs from different pollutants to be compared so that potential multiple benefits can be identified. CaRPow provides a transferable framework that can be used by water companies to cost-effectively target interventions under current conditions or under scenarios of land use or climate change.

1. Introduction

Variability in catchment water quality is an issue that impacts on many aspects of the environment and society. Improvements to water quality have resulted from the improved regulation of industries that discharge effluent into the water environment from an individual source (e.g. EU Urban Waste Water Directive 91/271/EEC). However the improved control of point sources means that increasing attention is being placed on diffuse sources of pollutants in catchments (Edwards and Withers, 2008). The spatially-diverse nature of diffuse pollution makes it difficult to pinpoint areas for regulation and investment and therefore an integrated catchment based approach has commonly been adopted for its control (Harris, 2013), e.g. the Watershed Approach Framework (USA) (EPA, 1996), Catchment Management Authorities (New South Wales, Australia) (NSW Government, 2003).

In Europe, this integrated approach forms the underlying management structure of the EU Water Framework Directive (WFD) which aims to achieve a 'good' ecological and chemical status for all EU water bodies (2000/60/EC; Holzwarth, 2002). Achieving the required water body status relies on the designated Competent Body (such as the national environmental regulator) outlining a programme of measures, within their river basin management plans, to tackle a range of pollutants which may be implemented by multiple organisations or stakeholders, which may include water companies.

Water companies as recipients of poor water quality and with their own regulatory issues have an increasing interest in controlling pollution at source using catchment management rather than

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relying on increased treatment. At the EU level this is consistent with Article 7 of the WFD which aims at "*avoiding deterioration in their* (Water Companies) *quality to reduce the level of purification treatment required in the production of drinking water*" (2000/60/EC). This, combined with encouragement from the water industry regulatory bodies and the perceived benefits of catchment management within the water industry (such as reducing costs of treatment, promoting sustainability and reducing greenhouse gas emissions) (UKWIR, 2012), have led to all of the major water companies in the UK adopting some form of integrated catchment management (Spiller et al., 2013). However despite national concerns about drinking water limits being breached by multiple pollutants, catchment management investigations have tended to be reactionary and to focus on a single pollutant issue in isolation. This potentially means that companies are not realising the full benefit of an integrated approach to improve raw drinking water quality.

Drinking water catchments often present an inherent mosaic of different land uses, soil types, geology and anthropogenic influences that promote heterogeneity in catchment pollutant processes. For catchment management to be effective and sustainable it is vital that interventions are carefully selected and targeted at Critical Source Areas (CSAs) that pose disproportionately higher risk than others (Strauss et al., 2007; White et al., 2009; Doody et al., 2012). Aside from improved effectiveness and reduced implementation costs, disruption to other catchment stakeholders will be reduced when compared to widespread implementation of interventions (Beharry-Borg et al., 2013).

The selection and targeting of measures has been supported by the development of a number of conceptual frameworks and models to aid stakeholder decisions. However, they have largely been developed with single pollutant issues in mind e.g. the Nutrient Export Risk Matrix (Hewett et al., 2004, 2009) or the CatchIS modelling framework (Brown et al., 2002). Frameworks have also been developed which highlight certain components of pollutant risk such as the SciMap modelling framework which makes an assessment of spatial risk based on hydrological connectivity in a catchment (Lane et al., 2009). Frameworks that concentrate on singular pollutants or risk components however do not always allow for the assessment of the range of pollutants that need to be considered by water companies. Where multiple pollutant frameworks have been produced, they have either been developed for specific land use and soil types (Granger et al., 2010) or tend to focus on a single component of risk (e.g. source comparison in Dawson and Smith, 2010).

The aim of this paper therefore is to develop and demonstrate a generic conceptual framework that allows comparison of the spatial and temporal drinking water quality risks associated with multiple pollutants. This will allow water utilities and their partners to proactively identify critical source areas for multiple pollutants and subsequently better select and target a programme of interventions.

This paper (i) identifies catchment process similarities between different pollutants as a basis for integrating multiple pollutants within a single framework; (ii) proposes a new conceptual framework (CaRPoW – Catchment Risk to Potable Water) to facilitate the selection and targeting of catchment interventions to address multiple pollutants, that meets the needs of water companies based on criteria developed with water company professionals and (iii) discusses the merits and drawbacks of using such a framework to select and target interventions.

2. Catchment heterogeneity and multiple pollutant processes

The development of this generic framework is based on the presumption that different pollutants sometimes show similarities in either their source, mobilisation or delivery and that this will result in common critical source areas. Building on work by Haygarth et al. (2005) and Granger et al. (2010) we took the key pollutants of concern to drinking water source protection and reviewed their processes within the Source-Mobilisation-Delivery continuum framework that describes the cascade of groupings of pollutant processes that lead to the contamination of drinking water sources (Haygarth et al., 2005). Source processes concern whether a pollutant occurs naturally or as a result of human intervention (Granger et al., 2010). Mobilisation relates to the mechanism(s) by which a pollutant moves from its source either in solution and/or attached to particulate matter. Finally the delivery component refers to the pathway that a mobilised pollutant takes to reach the receptor (water body). Pollutants reviewed include pesticides and nitrate, which have regulated limits under the EU Drinking Water Directive (98/83/EC), and Dissolved Organic Carbon (DOC), sediment and phosphorus which cause issues relating to disinfection by-products, turbidity and reservoir algal blooms, respectively.

2.1. Pesticides

The importance and strength of the source term for most pesticides depends primarily on the agricultural land use, which in turn determines the rate, frequency and timing of active ingredient application. The mobilisation and delivery of the active ingredients are then often primarily determined by hydrological events which can affect runoff, leaching and drain-flow (Leu et al., 2004; Reichenberger et al., 2007). Although less common, spray-drift and overspraying into water bodies can also result from poor pesticide spraying practices (Reichenberger et al., 2007).

Mobilisation can be both in particulate and soluble forms, and is influenced by both soil properties and the sorption strength and solubility of the pesticide (Wauchope et al., 2002; Gavrilescu, 2005). Soil organic matter and clay content determine sorption sites and soil physical properties such as porosity determine the water storage capacity and thus propensity of pesticide sorption (Spark and Swift, 2002; Arias-Estévez et al., 2008). Soil texture and topographical features such as slope, which affect erosion rates, influence mobilisation in particulate forms (Arias-Estévez et al., 2008). Rainfall intensity, duration and timing can influence the onset of soil detachment (particulate mobilisation), the mobilisation of freshly applied pesticides on the soil surface and pesticides in soil solution when soil moisture content is above field capacity (Kladivco et al., 2001; Nolan et al., 2008; Lewan et al., 2009).

Pesticides can be delivered to water bodies by high energy, low energy and non-hydrological delivery pathways. Again pesticide properties are key determinands, with low sorbing and soluble pesticides more likely to be delivered in low energy pathways such as throughflow and leaching (Kördel et al., 2008) and stronger sorbing and less soluble pesticides delivered through higher energy processes such as surface runoff and preferential flow (Riise et al., 2004; Reichenberger et al., 2007). Throughflow and leaching processes are likely to be more prevalent in lighter, sandier soils (Leu et al., 2004) and the higher energy runoff and preferential pathways associated with heavier clay soils that may be subject to artificial drainage (Akay and Fox, 2007; Brown and van Beinum, 2009). Precipitation characteristics, especially the timing and magnitude of the first rainfall event after application (Louchart et al., 2001; Guo et al., 2004), are important in the delivery of pesticides. The significance of non-hydrological processes, such as spray drift and volatilisation, are dependent on the proximity of application to surface water, spraying technique and the properties