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Risk assessment and prioritisation of contaminated sites on the catchment scale

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ABSTRACT

Contaminated sites pose a significant threat to groundwater resources worldwide. Due to limited available resources a risk-based prioritisation of the remediation efforts is essential. Existing risk assessment tools are unsuitable for this purpose, because they consider each contaminated site separately and on a local scale, which makes it difficult to compare the impact from different sites. Hence a modelling tool for risk assessment of contaminated sites on the catchment scale has been developed. The CatchRisk screening tool evaluates the risk associated with each site in terms of its ability to contaminate abstracted groundwater in the catchment. The tool considers both the local scale and the catchment scale. At the local scale, a flexible, site specific leaching model that can be adjusted to the actual data availability is used to estimate the mass flux over time from identified sites. At the catchment scale, a transport model that utilises the source flux and a groundwater model covering the catchment is used to estimate the transient impact on the supply well. The CatchRisk model was tested on a groundwater catchment for a waterworks north of Copenhagen, Denmark. Even though data scarcity limited the application of the model, the sites that most likely caused the observed contamination at the waterworks were identified. The method was found to be valuable as a basis for prioritising point sources according to their impact on groundwater quality. The tool can also be used as a framework for testing hypotheses on the origin of contamination in the catchment and for identification of unknown contaminant sources.

1. Introduction

Releases of organic chemicals to the subsurface are a significant threat to groundwater resources worldwide. To date 300 000 sites across the EU have been identified as definitely or potentially contaminated, but the European Environment Agency estimates that there may be as many as 1.5 million contaminated sites (European Environment Agency, 2007). The costs for investigation and clean-up of these sites are very high. In Denmark 24 000 contaminated sites were registered in 2005 and an additional 55 000 sites are estimated to follow within the next 40 years. The total expected cost of managing and remediating these contaminated sites is estimated to be 14.3 billion DKK (~2 billion euros) (Danish EPA, 2006; Kiilerich, 2006). The available resources for site investigation and clean-up are limited compared to the large number of contaminated sites. To meet the future demand for site clean-up, regulators therefore face the challenge of prioritising remediation efforts in order to ensure that the sites that pose the greatest risk to groundwater are remediated first. In this context, risk assessment is an important tool (Cushman et al., 2001).

Various methods and models exist for assessing the risk of groundwater contamination (Newell et al., 1996; Aziz et al., 2000; Spence, 2001; Davison and Hall, 2003). Most of these methods are based on generic standards, meaning that a contaminated site is considered to pose a risk if the resulting plume concentrations at some predefined point downstream of the source are above the water quality limit. Hence, the risk is

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assessed at a *local scale*. This approach makes it easy to evaluate whether a given contaminated site is a threat to groundwater and has for the last decade been the common practice in many countries including Denmark (Bardos et al., 2002).

Traditional risk assessment tools are unsuitable for prioritisation purposes because they consider the contaminated sites separately, and focus only on calculating plume concentrations at the local scale. This focus on local assessment allows for an identification of sites posing a risk to groundwater, but does not quantify the risk to water resources at a catchment scale. The risk of different sites can therefore not be compared, which is essential in performing a prioritisation. Additionally, these tools do not consider if, and to what extent, downstream receptors (drinking water supply wells, lakes, streams etc.) are affected by releases from contaminated sites. However, the motivation for carrying out remediation at specific sites is often governed by the measured impact or concern about future impact on water supply wells. Thus, it has been proposed to shift the focus from the local scale to a *catchment scale* and to assess the risk by evaluating the impact on the supply wells in the catchment (Einarson and Mackay, 2001; Frind et al., 2006).

Einarson and Mackay (2001) present a conceptual framework for risk assessment and prioritisation of contaminated sites in a groundwater catchment, and focus on the estimation of worst-case concentration in the abstracted water at a supply well. They propose the use of mass flux or mass discharge ($M\ T^{-1}$) estimates from the point sources within the catchment to do this. Only a few catchment-scale risk assessment models have been published (Table 1). Arey and Gschwend (2005) use a mass flux approach to predict the impact of different gasoline constituents on water supply wells based on average contaminated site conditions in the United States. Frind et al. (2006) developed a well vulnerability concept for quantifying the impact of contaminated sites within the capture zone of a well, where forward and backward transport modelling is used for generating intrinsic well vulnerability maps displaying different information (e.g. expected times of arrival of a contaminant, dispersion-related reduction in concentration and exposure time). Tait et al. (2004) present the Borehole Optimisation System (BOS) for identifying the optimum locations for new supply wells in urban areas, which is based on an estimation of the cumulative impact of a chosen contaminant from all identified sources relevant to the supply well in a given year. None of these screening models are designed for prioritisation purposes and they can not be used for determining which of the identified sources pose the greatest threat to a water supply.

Since contaminated sites vary greatly in complexity, in the amount of available data and type of contamination, there is a need for flexible source models that can be adjusted to suit any given contaminated site and its data availability. Frind et al. (2006) do not include a source model, but focus only on the protective characteristics of the pathway medium. For describing the ability of the pathway medium to dilute a potential contamination and reduce the impact on a supply well, a unit pulse is released at the pumping well within an inverted flow field. A backward-in-time advective-dispersive transport simulation then provides the impact on the well of a unit pulse released anywhere within the capture zone. BOS assumes that the contaminant source is only present in the vadose zone (Tait et al., 2004; Chisala et al., 2007), and in the model of Arey and Gschwend (2005), the source is conceptualised as a LNAPL pool present on the groundwater table. These source models are specific and thus are not sufficient, on their own, for describing the many different types of contaminated sites that may exist within the catchment. At the catchment scale BOS is the only model that considers the impact from multiple

Table 1

Comparison of screening models/methodologies for estimating contaminant impact on water supply wells

	Frind et al. (2006)	Tait et al. (2004)	Arey and Gschwend (2005)	CatchRisk
Local scale (source model)				
Modular and flexible design				X
Built-in database		X		
Source	Unit pulse *	Constant	Pulse	Constant; Decaying
Multiple types of contaminant		X	X (LNAPLs)	X
Source history		X		X
Degradation				First-order; Sequential
Sorption				X
Residual Phase			X	X
Catchment scale				
Catchment delineation	Backward transport modelling	Particle tracking		Particle tracking
Advection	X	X	X	X
Dispersion	X		X	Not needed
Degradation		First-order		First-order; Sequential; 2 degradation zones
Sorption		X	X	X
Dilution in supply well	X	X	X	X
Multiple contaminated sites	X	X		X
Hydrogeology	Complex multi-layer, multi-zone 3D groundwater model	Single-layer, multi-zone 3D groundwater model	Uniform flow field	Complex multi-layer, multi-zone 3D groundwater model
Impact on supply well	Time-dependent	Time-dependent; Cumulative	Static	Time-dependent; Cumulative; Relative contribution from different sources
Built-in uncertainty analysis	X (through dispersion)	X		

* By applying convolution, the unit pulse can be extended in space and time.