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Application of a contaminant mass balance method at an old landfill to assess the impact on water resources

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ABSTRACT

Old and unlined landfill sites pose a risk to groundwater and surface water resources. While landfill leachate plumes in sandy aquifers have been studied, landfills in clay till settings and their impact on receiving water bodies are not well understood. In addition, methods for quantitatively linking soil and groundwater contamination to surface water pollution are required. This paper presents a method which provides an estimate of the contaminant mass discharge, using a combination of a historical investigation and contaminant mass balance approach. The method works at the screening level and could be part of a risk assessment. The study site was Risby Landfill, an old unlined landfill located in a clay till setting on central Zealand, Denmark. The contaminant mass discharge was determined for three common leachate indicators: chloride, dissolved organic carbon and ammonium. For instance, the mass discharge of chloride from the landfill was 9.4 ton/year and the mass discharge of chloride to the deep limestone aquifer was 1.4 ton/year. This resulted in elevated concentrations of leachate indicators (chloride, dissolved organic carbon and ammonium) in the groundwater. The mass discharge of chloride to the small Risby Stream down gradient of the landfill was approximately 31 kg/year. The contaminant mass balance method worked well for chloride and dissolved organic carbon, but the uncertainties were elevated for ammonium due to substantial spatial variability in the source composition and attenuation processes in the underlying clay till.

1. Introduction

Waste disposal in landfills around the world threaten to pollute fresh water resources (EEA, 2007; Kjeldsen et al., 2002; Lisk, 1991). In Europe approximately 675,000 sites may have been contaminated by activities related to the handling of municipal and industrial waste (EEA, 2007), a significant part of these are landfill sites. In Denmark alone more than 2000 old landfills without leachate collection or liners have been mapped (Danish EPA, 2010). Older unlined landfills have preferably been located close to wetlands and streams, giving rise to impacts on both surface water and groundwater (Ford et al., 2011; Lambou et al., 1990; Lisk, 1991; Lorah et al., 2009). A better understanding of this impact is critical for successful implementation of the EU Water Framework Directive (2000/60/EC).

The potential impacts of landfill leachate entering a surface water system are: (1) the toxicity and eutrophication potential of ammonia (NH_3) (Camargo and Alonso, 2006), (2) oxygen depletion in the surface water by addition of dissolved organic carbon (DOC) and nutrients (Diaz, 2001; Kronvang et al., 2005), (3) accumulation of iron(III) on the fish gills (Teien et al., 2008), (4) the bioavailability and toxicity of iron(II) (Vuori, 1995), (5) the toxicity of inorganic trace elements (Lisk, 1991) and (6) the toxicity of xenobiotic organic compounds (XOCs) (Baun et al., 2004). The main leachate related problems for groundwater as a drinking water source were identified by Christensen et al. (2000) as ammonium (NH_4^+) and XOCs. Ammonium may due to long term leaching in high concentrations deteoriate groundwater quality, while the XOCs are problematic in lower concentrations due to their toxicity.

Attenuation processes and the impact on groundwater in sandy aquifers has been studied intensively (Christensen et al., 2001), while landfill studies in clay till geology and/or studies of discharge to surface water are few (Bjerg et al., 2011). From previous studies of contaminant transport in clay till, we know that the flow field may be difficult to assess due to significant geological heterogeneity (Gerber et al., 2001; Hendry et al., 2004; Mckay et al., 1998; Milosevic et al., 2012). It is important to document how attenuation processes and heterogeneity affect the magnitude of the contaminant mass discharge and thereby the impact on the receiving water body.

Mass discharge estimates have been applied to quantify the impact of landfills on multiple water resources by Douglass and Borden (1992) and Yusof et al. (2009). Douglass and Borden (1992) estimated the mass discharge to the Crabtree Creek by a

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summation of the mass discharge from base flow, storm flow and groundwater. This was done under the assumption that all groundwater eventually would discharge to the stream. Yusof et al. (2009) compared the contaminant mass discharge in river systems up and down stream of landfills, with the contaminant mass discharges from these landfills through a drain discharging to the river. They concluded that the effect of leachate on river water quality in their case could be estimated by monitoring the water chemistry in the river.

In this paper we present a method to evaluate the impact from a landfill situated in clay till on the surrounding water bodies. The method is expected to be used as a screening tool for landfills as part of a risk assessment related to implementation of the European Water Framework Directive. The paper will in particular address the following:

1. Application of historical and field data for landfill source characterization including spatial and temporal variation in leachate quality.
2. Quantification of the contaminant mass discharge from a landfill to the groundwater in a clay till geology.

2. Materials and methods

2.1. Study site: Risby Landfill

The study site was Risby Landfill, located in a forested area on the central part of Zealand, Denmark (Fig. 1). The area of the landfill is approximately 55–65,000 m^2 and the volume is 5–600,000 m^3. Risby Stream flows from east to west and is located north of the landfill. The landfill is unlined and has no leachate collection system.

2.1.1. Landfill history

Risby Landfill was in operation from 1959 to 1985. Between 1959 and 1969 there was no control of the waste disposal at the site (Thomsen, 2010). From 1970 to 1981 a control system was established but the landfill remained open to the public. During these periods, mainly household waste but also other waste mixtures was deposited. From 1981 to 1985, the landfill was used by the Danish Forest and Nature Agency and the waste types in this period were bulky-, garden- and construction waste. The development of Risby Landfill in space and time compared with waste types can be seen on Fig. 2. The deposition started in the northern part of the landfill. Limited amounts of waste were deposited during the first 10 years, but the deposition rates increased in the 1970s and most of the waste was placed in this decade.

Archive records suggest that chemical waste was disposed between 1945 and 1976, but this has been difficult to confirm. But it was common practice in Denmark in the 1960s and early 1970s to dump chemical residues at old landfills (Kjeldsen et al., 1998b). Because the northern part of the landfill was completed before 1976 it is most likely that chemical waste has been deposited there (Thomsen, 2010).

2.1.2. Geology

Risby Landfill is located in a region where repeated glaciations during the Quaternary period have had a significant effect on the geology (Frederiksen et al., 2003) (Fig. 3). The original terrain in the landfill area has an elevation of 16–23 mamsl (meters above mean sea level), and slopes down towards Risby Stream in the north. The Quaternary strata are approximately 20–30 m thick and consist of clay till embedded with sand lenses. Below the north eastern part of the landfill, larger sand lenses of up to 5 m in thickness have been observed. A continuous upper shallow aquifer associated with the sand lenses is not proven; it will therefore in the

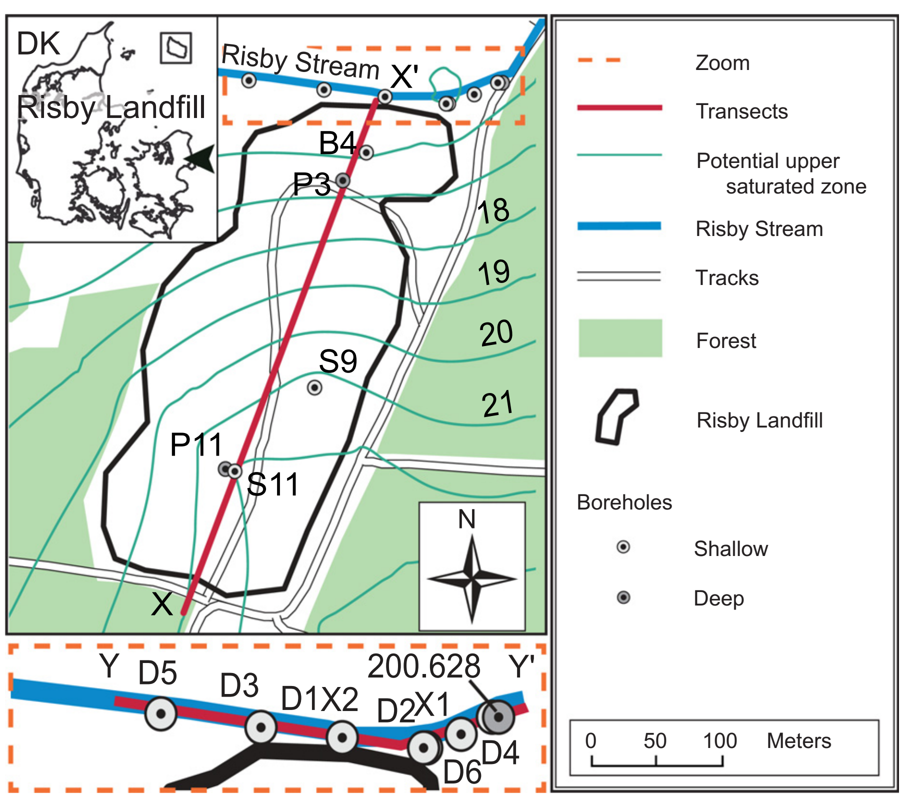

Fig. 1. Location and outline of the study site; Risby Landfill. Risby Stream runs from east to west and is located north of the landfill. The red line indicates the location of the geological transects presented on Fig. 3.