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Site-specific aftercare completion criteria for sustainable landfilling in the Netherlands: Geochemical modelling and sensitivity analysis

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A B S T R A C T

A novel, regulatory accepted approach is developed that enables competent authorities to decide whether landfill aftercare can be reduced or terminated. Our previous paper (Brand et al., Waste Management 2016, 56, 255–261, https://doi.org//10.1016/j.wasman.2016.07.038) outlines the general approach, that consists of a 10-year treatment phase (e.g., aeration, leachate recirculation), in combination with site-specific Environmental Protection Criteria (EPC) for contaminant concentrations in the landfill leachate after treatment. The current paper presents the unique modelling approach by which the site-specific EPC are derived. The modelling approach is based on the use of mechanistic multi-surface geochemical models covering the main sorption processes in soils underneath the landfills, and is composed of widely-accepted surface complexation models in combination with published “generic” parameter sets. This approach enables the consideration of the main site-specific soil properties that influence the attenuation of emitted contaminants. In addition, the sensitivity of the EPC is shown for variation of the main physicochemical-assumptions and policy-based decisions. Site-specific soil properties have been found to substantially determine the EPC and include soil-pH, dissolved organic matter, and iron-(hydr)oxide content. Apart from the sorption capacity of the local soil, EPC also depend strongly on the assumed dilution with local groundwater in the saturated zone. An important policy-related decision that influences the calculated EPC is the assessment period during which the groundwater is protected. The transparent setup of the approach using geochemical modelling, the explicit consideration of site-specific properties and the achieved regulatory acceptance may also stimulate application to landfills in other countries.

1. Introduction

Although increasingly more waste materials are recycled or re-used, landfilling remains necessary for those materials that have no beneficial use potential. However, management of existing and closed landfills is costly for society, due to long-term aftercare measures such as liner maintenance, everlasting monitoring and leachate treatment. Recently, the Dutch Sustainable Landfill Foundation, The Ministry of Infrastructure and Environment of the Dutch national government, and landfill operators have signed a so-called “Green Deal”, a project for three existing pilot landfills in order to test if source-oriented treatment techniques (e.g., irrigation, leachate recirculation, aeration) are sufficiently effective to reduce the remaining emission potential in the landfill to a level that does not pose an undesired risk to the environment (Brand et al., 2016). Three existing, predominantly inorganic landfills were selected as pilots for this project, on the basis of a number of criteria, including the potential for stabilization, and presence of a bottom liner (Brand et al., 2016). If the pilots are successful, competent authorities may decide to reduce or terminate the aftercare (Brand et al., 2016; Kattenberg and Heimovaara, 2011).

In order to judge whether the leaching of contaminants from a (treated) landfill has reached an environmentally acceptable level to reduce or terminate the aftercare, criteria with respect to the landfill leachate composition are established. Emissions to air are not part of the methodology (Brand et al., 2016). The site-specific “environmental protection criteria” (EPC), are maximum allowable concentrations (μg/l) of a wide range of substances in the landfill leachate, and are developed such that local groundwater quality is protected for 500 years. The EPC are calculated for a group of 12 inorganic contaminants (soluble salts, metals, metalloids and oxyanions) and over 40 organic contaminants (BTEX, PAH, VOX and mineral oil fractions). These criteria have been calculated

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based on a "source-path-receptor" approach and take into account site-specific attenuation factors that influence the transport rate of leached contaminants on the "pathway" between the "source" (the landfill) and the downstream "point of compliance" (POC, see Fig. 1).

Similar approaches have previously been followed to develop regulatory emission criteria for construction products and large-scale applications of (excavated) soil and sludge in the Netherlands, in force since 2007 (Kingdom of the Netherlands, 2007; Verschoor et al., 2006, 2008), and in Germany for recycled products (Dijkstra et al., 2013; Susset and Grathwohl, 2010). These approaches are not site-specific, but generic with respect to range of application. Comparable approaches to obtain aftercare completion criteria for landfills have been investigated but have not led to legislation yet (Laner et al., 2012a). Laner et al. established criteria in a case study for a limited set of mobile contaminants (Laner et al., 2012b).

This paper presents the technical modelling approach by which the site-specific EPC for the three selected pilot landfills are derived, and the sensitivity of the EPC for variation in physico-chemical parameters as well as policy-related choices and assumptions. As such, this paper is complementary to our previous publication of Brand et al. (2016) that outlines the general approach to derive EPC, with the focus on policy considerations and selection of environmental criteria.

The novel aspect of the modelling approach to derive the EPC is that it makes use of the substantial progress in geochemical modelling that was made over the past decade (Groenenberg and Lofts, 2014; Scharff et al., 2011), which enables the prediction of main sorption processes that emitted contaminants undergo in the soils underneath the landfills (Scharff et al., 2011). The unique site-specific character of the EPC is facilitated by the use of the "multi-surface" sorption model approach (Dijkstra et al., 2009; Groenenberg and Lofts, 2014; Groenenberg et al., 2012) covering the main sorption processes in soils, composed of widely-accepted surface complexation models in combination with published "generic" parameter sets. Due to its fundamental character, the multi-surface model approach has a more generic validity as compared to empirical models, and can therefore be applied to specific soils with widely different properties without prior fitting of model parameters (Dijkstra et al., 2004, 2009; Groenenberg et al., 2012). Through this approach, it is possible to derive EPC for a wide range of contaminants simultaneously, based on site-specific soil properties. In the model approach, the local soil acts as a temporary buffer for contaminant migration, and its sorption capacity depends on site-specific properties such as pH, organic matter, and iron-(hydr)oxide content. Organic contaminant retardation is modelled in a simplified manner using linear distribution coefficients (K_d) based on published K_{oc} values and site-specific solid and dissolved organic carbon.

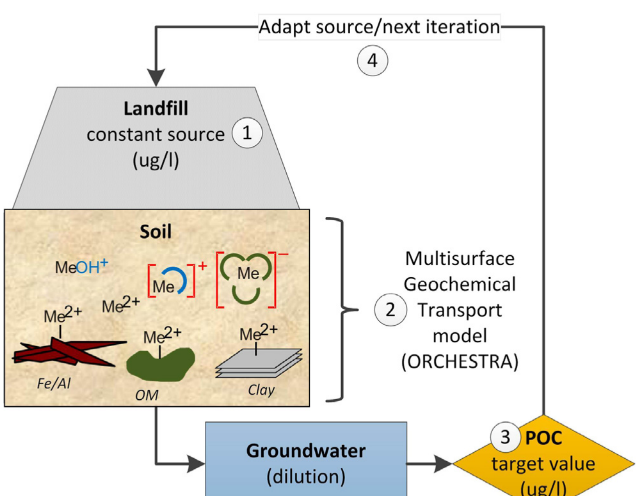

Fig. 1. Methodology to calculate site-specific emission protection criteria (EPC) for the three pilot-landfills (Figure adapted from Brand et al., (2016)). An iterative calculation process (step 1 to 4) results in criteria for the contaminant concentrations in the source (landfill leachate) that do not exceed groundwater quality criteria at the point of compliance (POC) downstream the landfills, see text for explanation. A "multisurface" geochemical model approach is used to estimate site-specific retardation in soil, based on solution speciation and sorption Fe/Al hydroxides (Fe/Al), natural organic matter (OM), and clay (illustrated for a hypothetical metal cation, Me^{2+}).

2. Materials and methods

2.1. General model approach

Principles and assumptions of the approach were kept as similar as possible to that used for the development of emission limits for construction products and large-scale applications of (excavated) soil and sludge in the Dutch Soil Quality Decree (Verschoor et al., 2006). Conceptually, the approach (Fig. 1) consists of three model compartments: (1) The "source term" represents the assumed quantity and composition of landfill leachate entering the soil and groundwater compartment. Ultimately, it is the source term for which EPC need to be established. (2) Reactive transport through soil and groundwater, during which retardation and dilution of the released contaminants occurs ("pathway"); (3) The "point of compliance (POC)", which is the location downstream the landfill where the local groundwater target values must be met within a certain assessment period. The approach in Fig. 1 is one-dimensional, i.e., spatial heterogeneity of site-specific parameters is not explicitly taken into account. An iterative calculation process (step 1 to 4) results in maximum concentrations that can be allowed in the source (i.e., the EPC) that do not result in exceedance of groundwater targets at the point of compliance (POC) within the specified assessment period (500 years (Brand et al., 2016), see below). Step 1 is the starting point, in which initial estimates for the EPC in the source term are made, using the groundwater target concentrations as initial estimate. In step 2, the reactive transport in soil and groundwater is calculated using the geochemical model (see below). In step 3, the calculated concentrations at the POC after 500 years are compared to the groundwater target value in a spreadsheet. If the calculated concentration differs from the groundwater target value due to retardation and dilution processes a new estimate of the source term concentration is made (step 4), followed by a next calculation. This process continues until the concentration in the source term in step 1 reflects the maximum value at which the groundwater limit value at the POC at 500 years is not exceeded (e.g., as in Fig. 2). These steps are followed for all substances considered in the model simultaneously, i.e. taking competition for sorption sites and possible precipitation reactions into account. Because of the non-linearity of the sorption and precipitation processes, steps 1–4 were repeated about 20–30 times to obtain a set of maximum concentrations in the source such that the concentrations of the contaminants at the POC between 0 and 500 years (μg/l) are within 1% difference from the groundwater targets (μg/l). The final concentrations in the source term are then defined as the EPC. Table S2 summarizes the main choices in the approach and their motivation, and whether these are generic or site-specific (see also Brand et al. (2016)). A detailed description of the three pilot landfills, hereafter denoted as site #1, #2 and #3, is found in Brand et al. (2014, 2016) and references therein.