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Screening tool to evaluate the vulnerability of down-gradient receptors to groundwater contaminants from uncapped landfills

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A B S T R A C T

A screening tool for quantifying levels of concern for contaminants detected in monitoring wells on or near landfills to down-gradient receptors (streams, wetlands and residential lots) was developed and evaluated. The tool uses Quick Domenico Multi-scenario (QDM), a spreadsheet implementation of Domenico-based solute transport, to estimate concentrations of contaminants reaching receptors under steady-state conditions from a constant-strength source. Unlike most other available Domenico-based model applications, QDM calculates the time for down-gradient contaminant concentrations to approach steady state and appropriate dispersivity values, and allows for up to fifty simulations on a single spreadsheet. Sensitivity of QDM solutions to critical model parameters was quantified. The screening tool uses QDM results to categorize landfills as having high, moderate and low levels of concern, based on contaminant concentrations reaching receptors relative to regulatory concentrations.

The application of this tool was demonstrated by assessing levels of concern (as defined by the New Jersey Pinelands Commission) for thirty closed, uncapped landfills in the New Jersey Pinelands National Reserve, using historic water-quality data from monitoring wells on and near landfills and hydraulic parameters from regional flow models. Twelve of these landfills are categorized as having high levels of concern, indicating a need for further assessment. This tool is not a replacement for conventional numerically-based transport model or other available Domenico-based applications, but is suitable for quickly assessing the level of concern posed by a landfill or other contaminant point source before expensive and lengthy monitoring or remediation measures are taken. In addition to quantifying the level of concern using historic groundwater-monitoring data, the tool allows for archiving model scenarios and adding refinements as new data become available.

1. Introduction

In 2010 there were 1908 operational municipal landfill facilities in the U.S. which received 135 million tons of waste and more than 10,000 closed landfills in the U.S. (USEPA, 2011). Problems associated with open and closed landfills include gas emissions, contaminated leachates, physical hazards, aesthetic issues, and others. These issues can extend beyond the landfill boundaries and affect surrounding urban, agricultural and undeveloped areas. The range of possible contaminants includes volatile organic chemicals; dissolved organic matter; inorganic macro-components such as calcium, magnesium, manganese and sulfate; heavy metals such as cadmium, chromium, lead and zinc; and xenobiotic organic compounds such as aromatic hydrocarbons, phenols and pesticides (Kjeldsen et al., 2002). Further, a closed landfill may be targeted for redevelopment for a variety of other purposes. For example, of 55 redeveloped landfill sites in Florida, 56.4% have been developed as recreational facilities, 27.3% for commercial use, 9.1% for residential development, and 7.3% for schools (Martin and Tedder, 2002). Therefore, it is essential to determine whether landfill leachate contaminants will negatively affect the underlying land and surrounding areas. This requires information about the composition and concentrations of groundwater contaminants, an understanding of subsurface hydrologic conditions, and tools to unify these factors to provide assessments of the risks these contaminants pose to nearby receptors, such as streams, wetlands and existing or proposed residential areas.

Landfill risk assessment is an evolving science, and there is not currently a universally accepted integrated risk assessment methodology that can be applied to landfill gas, leachate and

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degraded waste. Butt et al. (2008) reviewed 19 publications that prescribe landfill risk assessment procedures, and concluded that none addressed all issues related to risks associated with landfills and possible remedies. Nonetheless, regulatory guidelines have been issued that describe steps that should be taken when conducting landfill risk assessments. The USEPA Ecological Risk Assessment Guidance for Superfund (1997) and "Principles" follow-up document (1999) describe an eight-step process for performing landfill risk assessments:

1. screening-level problem formulation and ecological effects evaluation,
2. screening-level exposure estimate,
3. baseline risk assessment problem formulation,
4. study design and data quality objective process,
5. field verification of sampling design,
6. site investigation and analysis phase,
7. risk characterization, and
8. risk management.

Steps 1 and 2 define a *screening process*, where a decision is made to either take no action or to proceed with a full risk assessment. The New Jersey Department of Environmental Protection (NJDEP) (2012) published a risk assessment document based on this USEPA approach. Here, they defined an ecological evaluation (EE) as the preliminary screening phase, which is followed either by no further action or a full environmental risk assessment. The EE includes assembling information about the site and potential environmentally sensitive receptors, and determines whether contaminants of concern and a migration pathway are present.

The purpose of this investigation was to develop and evaluate a screening method for assigning preliminary levels of concern for the potential input of contaminants from landfills to nearby human or ecological receptors; to document the attributes and limitations of the transport model used in the method; and to demonstrate the method. The intent was to create a method, based on an idealized modeling approach, whereby preliminary levels of concern can be applied to landfills quickly and efficiently based on minimal input data. The screening method provides a formalized implementation of the NJDEP EE. Water-quality data from landfill monitoring wells are used to identify contaminants of concern, concentrations are compared to regulatory levels, and groundwater contaminant transport (the migration pathway) is quantified at a screening level with the transport model. The level of concern is stated as "unknown" if water-quality and receptor data, number or location or wells, or values of parameters needed to simulate transport are insufficient. Otherwise, the level of concern is defined based on the model-simulated concentrations of contaminants at the receptors under steady-state conditions. If this screening process indicates that substantial concentrations of contaminants could reach receptors, then additional monitoring, modeling or remedial action (e.g. a full environmental risk assessment) may be appropriate.

Analytical and numerically-based applications for predicting transient and steady-state contaminant transport are available, such as those listed by the Colorado School of Mines Integrated Groundwater Modeling Center (2014) and the USEPA Center for Subsurface Modeling Support (2014). Data requirements, user expertise, and time and effort required to develop models are extensive for many of these applications, and therefore their use as rapid screening tools is not practical. However, models based on the approximate, analytical solution of Domenico (1987) are used in contaminant-transport screening applications such as Quick Domenico (Pennsylvania Department of Environmental Protection, 2008), Biochlor (Aziz et al., 2000), Bioscreen (Newell et al., 1996), and Footprint (Ahsanuzzaman et al. 2008). These models are run as Microsoft Excel spreadsheet applications, and provide rapid estimates of contaminant concentrations in plumes downgradient of sources. This approach was used in the screening method presented here. An improved, more capable version of the Quick Domenico spreadsheet implementation was developed, with additional features that were specifically required for rapid screening of any number of landfills with lengthy lists of potential contaminants and down-gradient receptors of various types and distances from the source, and for efficient archiving of all simulation inputs and results for future reference or modification.

The screening method is illustrated by evaluating levels of concern posed by 30 closed, uncapped and unlined landfills in the Pinelands National Reserve (PNR) in southern New Jersey (Fig. 1). The PNR occupies more than one million acres in seven counties (New Jersey Pinelands Commission, 2014). This area is protected from unrestricted development to preserve its unique and fragile ecosystem (Zampela et al., 2008). Most of the PNR is underlain by the Kirkwood-Cohansey aquifer system, which underlies 3000 square miles of the New Jersey Coastal Plain (Watt, 2000). The Cohansey Formation is an unconfined sand-and-gravel aquifer with discontinuous interbedded clays (Owens et al., 1988). The Kirkwood Formation is a fine to medium sand (Owens et al., 1988). Rhodehamel (1973) reported that the hydraulic conductivity of the Kirkwood-Cohansey aquifer system ranges from 90 to 250 ft/d, and values for specific locations were obtained from published regional groundwater flow models and the transmissivity ranges from 4000 to 8300 ft^2/d. The storage coefficient ranges from 3×10^{-4} to 1.0×10^{-3}.

Site characterization and contaminant (water-quality) data were provided by landfill operation and closure documents and monitoring well reports provided by the NJDEP. Potential receptors were identified as streams, wetlands and residences near the landfills as determined by existing GIS coverages.

Understanding the residual effects of these landfills on underlying groundwater and down-gradient streams, wetlands and residences is of interest to the New Jersey Pinelands Commission, which in conjunction with the NJDEP has regulatory responsibility over these landfills. It is anticipated that results from this screening method will assist the Commission with future land-use decisions and in identifying the need for implementation of engineering controls.

2. Methods

2.1. Screening model theory and development

A groundwater solute-transport model based on the analytical model of Domenico (1987) was used to simulate subsurface contaminant transport from landfills to down-gradient receptors. It assumes first-order decay, linear sorption–desorption, constant source strength, and steady groundwater flow. The approximate analytical solution of Domenico, unlike exact analytical and numerical solutions, is amenable for use as a spreadsheet application.

2.1.1. Model description and applicability

Three-dimensional (3D) non-steady-state solute transport of a dissolved solute through porous media as presented by Domenico and Robbins (1985) and enhanced with solute attenuation and retardation can be expressed as:

$$\frac{\partial C}{\partial t} + \frac{v}{R}\frac{\partial C}{\partial x} - \frac{D_x}{R}\frac{\partial^2 C}{\partial x^2} - \frac{D_y}{R}\frac{\partial^2 C}{\partial y^2} - \frac{D_z}{R}\frac{\partial^2 C}{\partial z^2} + \lambda C = 0 \quad (1)$$

where C is the concentration of a solute species, v is the specific discharge, and D_x, D_y and D_z are dispersion coefficients in the x, y and z dimensions, and λ is the first-order decay constant of the solute. The

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