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INTRODUCTION

In the UK, environmental regulators require Hydrogeological Risk Assessments for landfills as part of the permitting process, to demonstrate compliance with both the Landfill Directive (EU, 1999) and Environmental Permitting Regulations. In April 2010, the Environmental Permitting Regulations for England and Wales (UK government, 2010) were extended to include some of the provisions of the Groundwater Daughter Directive (EU, 2006), with emphasis on pollution prevention. Under the regulations, Hydrogeological Risk Assessments form part of the "prior examination" of a discharge from a landfill to groundwater (Environment Agency, 2003).

Although both operational and closed landfills with environmental permits must now comply with the regulations, many sites have a long history and include older phases, which were constructed to "dilute and disperse", alongside modern engineered cells with liner, control and management of leachate and gas, cap and drainage. In addition, many of the older sites started as infill of a void created by sand and gravel extraction, in hydrogeological environments which would be considered too vulnerable for landfill by modern standards. Although infiltration into the older cells can be reduced by capping, the inevitable loss of leachate to ground results in a complex interaction between historical and ongoing contaminant sources. This makes it difficult to distinguish the impacts of different phases and complicates compliance with regulations.

The standard approach to Hydrogeological Risk Assessment for landfills (Environment Agency, 2003) includes justification of the risk assessment method, consideration of the potential impacts over the entire lifecycle of the landfill, selection of priority contaminants to be modelled, creation of a conceptual model of the site, numerical modelling, completion criteria and a monitoring scheme. LandSim v 2.5 (Golder Associates, 2003) is most frequently used to model the potential contamination impacts, because it is considered to be the regulator's preferred tool. LandSim uses a probabilistic approach to simulate leachate production and chemistry in the landfill, followed by migration and leakage through the base of the landfill and the unsaturated zone.

In order to represent uncertainty and provide the regulators with a precautionary evaluation of potential risks to groundwater, input parameters are represented by the use of conservative probability distribution functions to describe site specific characteristics and model results are usually considered at the 90th percentile, over a prolonged time period. Although the model is comprehensive, it is inevitably simplified, thus for sites with a long and complex operational history, simulation of contaminant breakthrough and concentrations may not fit with monitoring data. These issues are illustrated with data and modeling results for a closed and capped landfill in eastern England.

LANDFILL SITE

The site was a sand and gravel pit until the early 1970s when it began to accept non-hazardous domestic, commercial and industrial waste. The landfill remained operational for over 30 years, with five main phases of disposal (Mott MacDonald, 2010). Each phase incorporated different design details, as the technology or current practice progressed. This lack of consistency in engineering is typical of the UK's older landfill sites.

As the overlying Neogene and recent sediments were mostly removed by quarrying, the landfill site lies directly on the Cretaceous Upper Chalk, a fractured white limestone with a fine grained, porous matrix, which forms the major aquifer in Eastern and Southern England. A simplified conceptual model is illustrated in Figure 1.

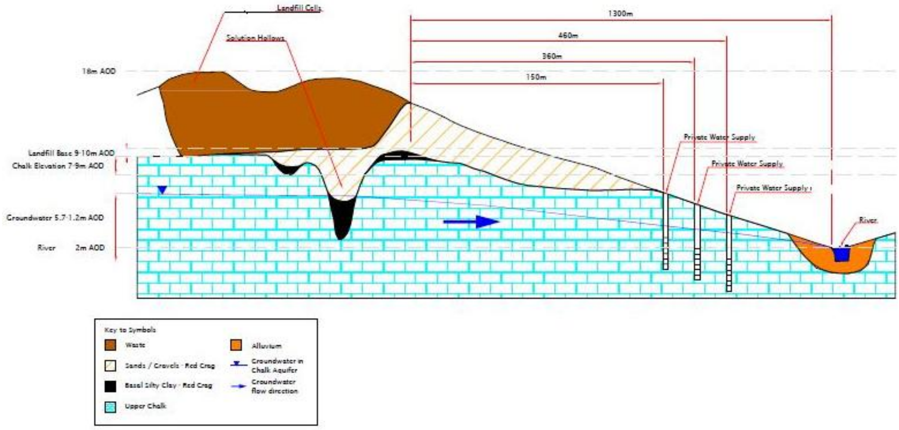

Figure 1. Schematic Cross section and Conceptual Site Model.

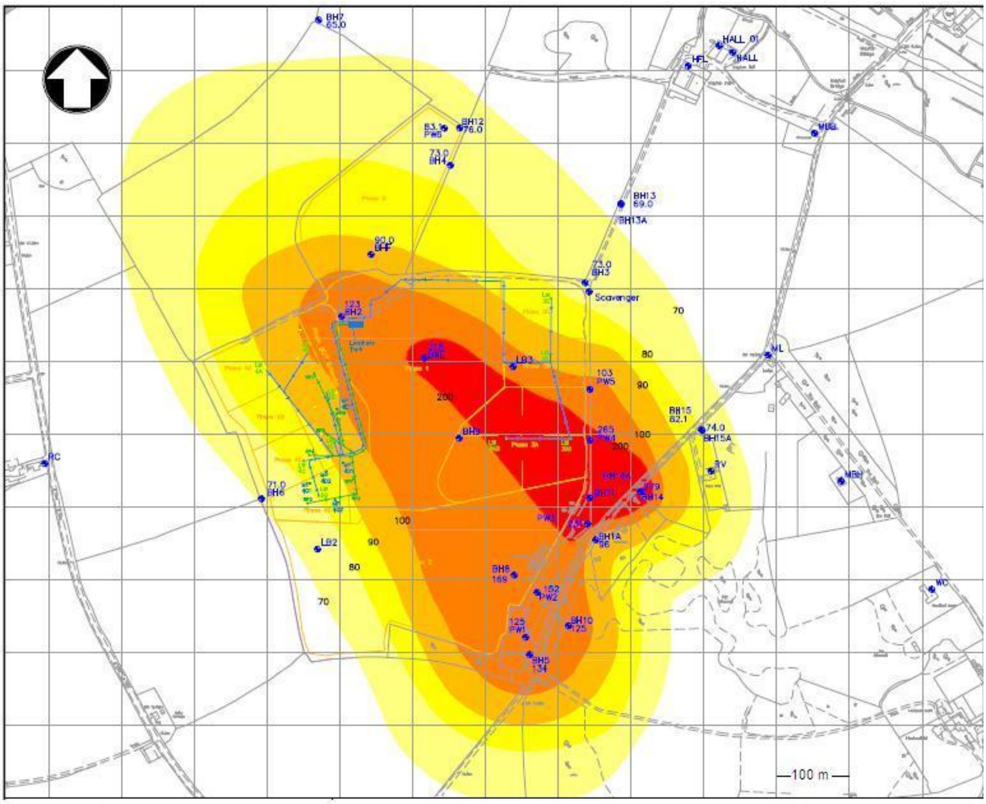

Figure 2. Observed Chloride concentrations (mg/l) in 2009.

Over 20 years of monitoring data indicates that groundwater flow is dominantly to the south east. The distribution of landfill derived substances, especially ammonia and chloride (Fig. 2), is consistent with this inferred flow direction but shows considerable lateral dispersion, although this is partly due to the large source area. The distribution also implies that preferential flow pathways may be active, and that the older, unlined phases are the main source areas. The time series data (Fig. 3 and 4) also shows that retardation is occurring, even for conservative species.

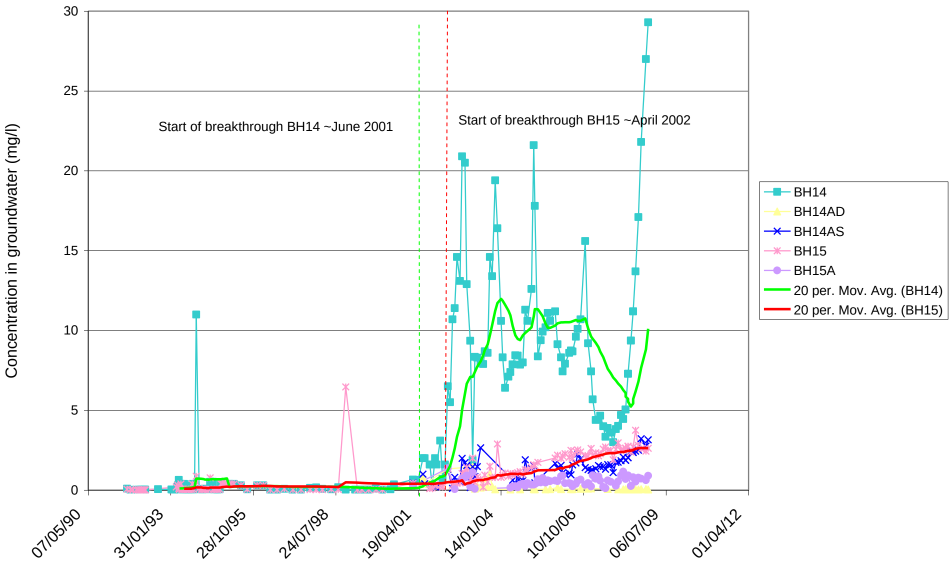

Figure 3. Observed concentrations of Ammonia with time in Chalk aquifer.

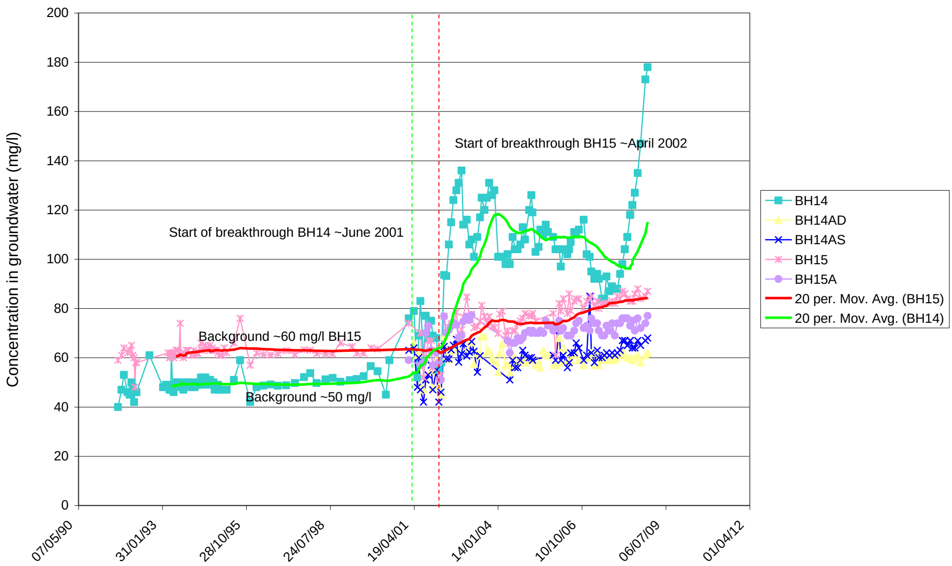

Figure 4. Observed concentrations of Chloride with time in Chalk aquifer.

APPROACH TO MODELLING

Based on the initial conceptual model, the saturated zone of the Chalk was represented in LandSim with high permeability, a low effective porosity and dispersion, thus representing rapid flow and contaminant transport in the fissure network only. Using these data, the simulated breakthrough of inorganic species was extremely rapid, with a sharp rise in concentrations, and quite different to the observed trends.

As the initial results were unrealistic, concerns about potential groundwater contamination required an alternative approach to risk assessment and predictive modelling of contaminant concentrations hydraulically downgradient of the landfill. A rapid assessment was essential, so the Remedial Targets Worksheet (Environment Agency, 2006) was used to simulate the 1-D migration of dissolved contaminants in the aquifer along several flow lines, with the source based on measured groundwater concentrations at the landfill boundary. Although this is a simplified model, it includes attenuation by dispersion, retardation and biodegradation. A good fit to observed breakthrough times and concentrations was achieved, using an effective porosity of 0.3 and hydraulic conductivity of 2 m/d for the Chalk aquifer. These values are consistent with local measurements, but differ from the accepted understanding of properties of the solution enlarged fractures in the aquifer's main flow zone. The interpretation is that the apparent retardation is due to diffusion from fractures into the matrix blocks, which have a total porosity of 0.35, and that transport is occurring through a network of small fractures in the upper part of the saturated zone. It was also apparent that ammonia is only slightly retarded, relative to chloride, close to the landfill, as demonstrated by Figures 3 and 4. This may be due to the heavy loading of ammonia and is consistent with the observations of Erskine (2000).

The results from the sensitivity analyses were used as the input to Landsim for the groundwater pathway through the Upper Chalk. This allowed a more realistic prediction of future risks to local abstractions and a baseflow fed river.

CONCLUSIONS

Although the LandSim model is capable of simulating a wide range of processes in and around a landfill and is the standard UK model for hydrogeological risk assessment, it is essential to check the results against observations and adjust input values to improve the agreement between model and observations. When the results do not fit well, a simpler model can be extremely useful for rapid sensitivity analysis and testing of the conceptual model. In this case, a simple 1-D model showed that the accepted model of a dominantly fractured aquifer, with high permeability and low effective porosity, is not realistic for a 30 year period with significant contaminant loading from the landfill. Diffusion into the matrix the upper part of the saturated zone is significant and results in an effective porosity which is close to the total porosity of the aquifer. The insights gained from the simplified model can then be used to constrain the data input to the more sophisticated LandSim model, thus generating greater confidence in the predictions.

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