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LandSim 2.5

groundwater risk assessment tool
for landfill design

ENVIRONMENT AGENCY

Introduction

The EC Groundwater Directive (80/68/EEC) (implemented via Regulation 15 of the Waste Management Licensing Regulations 1994 and the Groundwater Regulations 1998) requires "prior investigation" for activities involving the discharge of listed substances to groundwater. Technical precautions must be taken to prevent the discharge of List I substances to groundwater and to ensure that List II substances do not cause pollution. The recently adopted Landfill Directive (99/31/EC) requires pollution to be prevented during the entire life-cycle of the landfill. Risk assessment tools for determining the necessary technical precautions to protect groundwater at landfills must therefore be able to take account of the inevitable future failure and degradation of active engineering and management control systems (for more information see Reference 1).

The LandSim software model has been developed for the Environment Agency to provide probabilistic quantitative risk assessments of the performance of specific landfill sites in relation to groundwater protection. Since 1996 it has been used as a relatively simple tool to evaluate leakage of leachate from landfills, attenuation in the unsaturated zone, and dilution and contaminant transport in the saturated zone. LandSim allows landfill operators and regulators to consider the environmental performance of different liners (e.g. compacted clay versus HDPE/clay) and leachate collection systems, and to take account of the large variety of geological and hydrogeological regimes.

LandSim uses the Monte Carlo simulation technique to create parameters for use in the model calculations by random selection from a pre-defined range of possible input values (probability density functions). This process is repeated many times to give a range of output values. This probabilistic methodology allows improved quantification of uncertainty within the geological environment, the performance of specific landfill lining systems, and leachate chemistry (see Reference 2).

LandSim 2.5 – performance in the long term

Following implementation of the Landfill Directive (LFD) it is necessary to be able to model variations in the performance of lining systems over the entire lifetime of a landfill. Modern liner materials (e.g. high density polyethylene (HDPE) geomembranes) are expected to function effectively for hundreds of years before degradation leads to increased leachate leakage. However, since the timescale for stabilisation of many wastes is believed to exceed this time period, the flushing of contaminants from landfills is likely to continue after the liner has failed. LandSim 2.5 extends the capability of the existing model (v.2.02) by considering changes in the integrity of engineering and other active management control measures throughout the period (centuries) that landfills have the potential to pollute.

The sophisticated approach to simulating changes in leachate quality over time that was introduced for the LFD waste acceptance criteria negotiations has been included in LandSim 2.5.

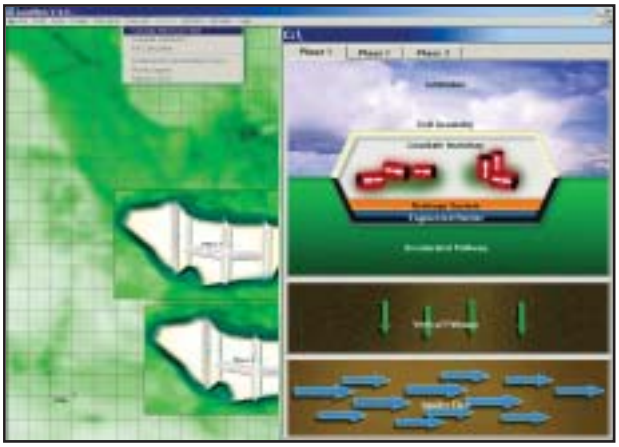

Figure 1. LandSim 2.5 conceptual model

Program outline

LandSim 2.5 is coded in the C++ programming language. In common with earlier versions, it has been designed to enable groundwater risk assessments to be carried out by experienced professionals with a good background in landfill engineering, hydrogeology and risk assessment but without the need for an in-depth knowledge of programming. A cartoon (Figure 1) guides you along the path of contaminant transport from the engineered landfill to a groundwater receptor.

At each stage along the pathway, you are asked to enter data that enables LandSim 2.5 to determine the rate of contaminant migration. Parameters are assigned to the model using pop-up dialogue boxes (Figure 2) accessed by clicking on active areas of the cartoon, or from drop-down menus, or through a data entry wizard. To prevent unnecessary data entry, the dialogue boxes are customised to the chosen landfill design.

LandSim 2.5 is compatible with data files prepared in earlier versions, although additional information must be entered.

LandSim 2.5 conceptual model

LandSim 2.5 continues to be based on the same site conceptual model as previous versions (Figure 1), which must be appropriate for the landfill being assessed (for guidance on conceptual models, see Reference 3). The landfill is assumed to be above the water-table. The receptor should not be too far from the site as the model output becomes less precise with increasing distance. Landfills located on highly sensitive aquifers are likely to require the use of more sophisticated flow and contaminant transport models (see Reference 4).

Model run options

Risk assessments using LandSim 2.5 should be conducted in two stages.

1. Hydraulics: Evaluate whether the drainage system can maintain a leachate head below the permitted maximum. This is a hydraulics model, constructed and run in the same way as in LandSim 2. Contaminant concentrations are not predicted at this stage.

2. Predict the impact on groundwater quality from the landfill: Contaminant concentrations are calculated at specified receptors over time. LandSim 2.5 takes account of degradation of the synthetic components of cap and basal lining systems and includes a new source term model. The conceptual models for cap and liner degradation are shown in Figures 3 and 4.

LandSim 2.5 includes all of the functionality of earlier versions such as:

- modelling of multiple phases and landfill sites;
- receptor for each phase plus the combined effect of all phases on a user-defined receptor;
- many different lining systems included;
- contaminant concentrations at the base of the unsaturated zone and in groundwater;
- retardation in unsaturated zone and aquifer;
- biodegradation of organic contaminants;
- consideration of background water quality;
- longitudinal dispersion in all pathways;
- flexibility in defining probability density functions (PDFs) for input parameters;
- Laplace transform technique used to solve the advection–diffusion contaminant transport equation;
- requirement to justify input parameters;
- ability to save and export results.

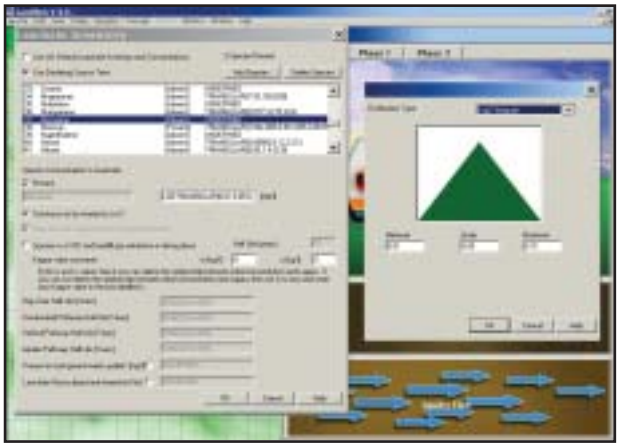

Figure 2. Data entry box (leachate concentrations)

Main changes introduced for LandSim 2.5:

- degradation of FML (flexible membrane liner) component of caps and liners;
- loss of active operational/institutional control;
- contaminant-specific declining source term;
- new leachate concentration ranges;
- biodegradation allowed in all pathways;
- attenuation in mineral component of liners;
- option to input Darcy flux.

Degradation of engineering

The inevitable physical and chemical breakdown of the FML components of caps and liners in the long term will cause increased infiltration and leakage of leachate. The conceptual model for FML degradation is shown in Figures 3 and 4.

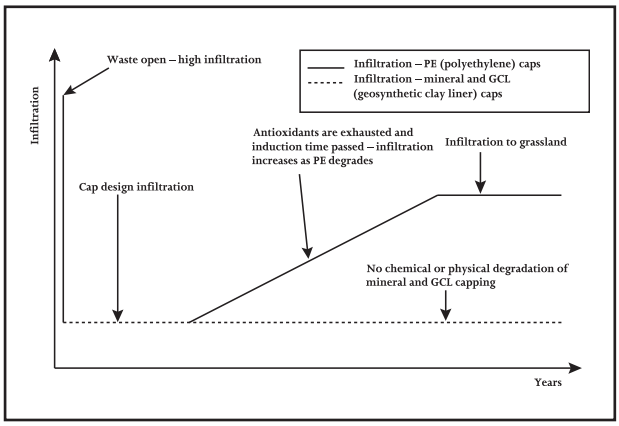

Figure 3. Conceptual model of cap degradation

Loss of operational/institutional control

While an operator or regulator has control of a landfill site it should be maintained in accordance with permit conditions. This period of management control typically applies to the duration of landfilling and the period of financial provision following closure of the site. At some point in the future management control will cease, if, for instance, the operator is no

longer in business and the period of financial provision has expired. Until the end of management control, the leachate head is fixed at the permitted level. After this time, leachate accumulation (leachate head) is determined by the balance between infiltration through the cap and leakage through the basal liner.

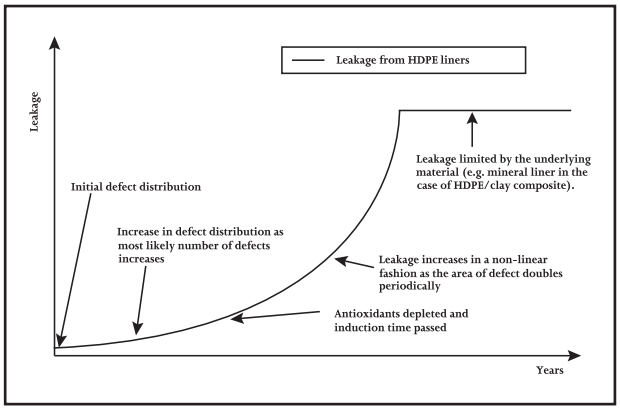

Figure 4. Conceptual model of liner degradation

Contaminant-specific source term

The new declining source term for non-volatile substances reflects the physical and chemical characteristics of individual contaminants. This approach is simulated using the *kappa* value, which is related to the contaminant–waste partitioning coefficient.

Research has shown that volatile organic compounds are removed from landfills via gas extraction systems, as well as partitioning into leachate; this is reflected in the variation of leachate quality over time.

Leachate management

The volume of leachate being re-circulated can be specified. The amount of leachate needing treatment and re-circulation or off-site disposal will be calculated.

Retardation

Partition coefficients (K_d) are used for the retardation of inorganic contaminants. Organic contaminants are normally modelled using partition coefficients to organic matter (K_{oc}) rather than soils. Partition coefficients must be appropriate for the system (leachate and soil/rock) being considered.

Biodegradation

LandSim allows the biodegradation of organic compounds. A decay rate (half-life) can be specified for each pathway (liner, unsaturated zone, vertical pathway, aquifer). This function must be used with caution, and only where it is realistic that the conditions are likely to be favourable for biodegradation.

List I substances - compliance with the Groundwater Directive

Contaminant concentrations can be calculated immediately prior to entry into groundwater, that is at the base of the unsaturated zone. Since the discharge of List I substances to groundwater is prohibited, this feature is essential to assess compliance with the Groundwater Directive.

Background groundwater quality

Background groundwater quality can be considered by LandSim. This may affect the degree of additional contaminant loading that is acceptable.

Multiple sites

Multiple sites can be modelled to reflect the common situation of new facilities being extensions to existing sites. The cumulative impact on groundwater can be predicted rather than just the impact of the new site. Each individual site or phase can have different infiltration values, cell geometries, lining systems, leachate quality and unsaturated zone properties (e.g. thickness).

Plan view plume generator

An indication of the likely development of any contaminant plume can be viewed as a colour-coded contour plan.

Probability density functions

There is considerable flexibility in the type of distribution used for most input parameters.

Saving and export of results

The results of model runs can be saved for later reloading, and some results can be exported for use in other modelling packages: leakage values, concentrations at the base of the liner system and concentrations at the base of the unsaturated zone.

User interface

The size of phases and receptor location can be easily changed. All inputs must be explicitly justified, while the output and printed record are locked together with a filename/timestamp system for audit purposes.

LandSim 2.5 model outputs

These can be divided into three sections: hydraulics, travel times and contaminant concentrations at specified locations and times (Table 1).

Table 1. | Outputs from LandSim 2.5

Property	Output
Hydraulics	Leachate head: Can the site operate within its licence conditions? Is the drainage system adequate?
	Flow to leachate treatment plant and any surface breakout
	Leakage through the liner and dilution in the aquifer
Travel times	Time for peak concentrations at specified receptors
Contaminant concentrations (over time)	In the source leachate
	At the base of the unsaturated zone
	At the monitoring well for each phase (5 metres downgradient)
	At the compliance point for the whole site

Hardware and software requirements

To run LandSim 2.5, you need an IBM compatible PC with a processor speed of at least 800 MHz and 128 MB of RAM. The software has been developed to run under Windows 2000. Users will need 30 MB of hard disk space for installation and for temporary files during simulations.

Guidance manual and technical support

An addendum to the LandSim 2 guidance manual (R&D Publication 120) has been produced for LandSim 2.5. A technical report that contains a detailed explanation of the evolution of LandSim 2.5 is available from www.landsim.com (Reference 5). For problems running the program or for technical enquiries, Help files are available within LandSim either from the main menu or through buttons in each input window. Full technical support for LandSim is offered by Golder Associates (UK) Limited through a help desk.

Obtaining LandSim 2.5

LandSim 2.5 can be purchased from Golder Associates:
Tel: 0115 9456 544
Fax: 0115 9456 540
E-mail: landsim@golder.com

A free demonstration version of LandSim 2.5 can be downloaded from www.landsim.com and the Agency website www.environment-agency.gov.uk.

Project manager

The Environment Agency's Project Manager for LandSim 2.5 was Dr Hugh Potter, National Groundwater & Contaminated Land Centre.

Further information

NGWCLC Project GW/03/09 was funded by the Agency's National Groundwater & Contaminated Land Centre and the Landfill Directive Project. Further information can be obtained from the R&D Management Coordinator (Waste Programme): Tel: 0117 9142 783; Fax: 0117 9142 673.

References

1. Environment Agency (2003) Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels. Report LFTGN01.

2. Environment Agency (2001) Guidance on Assigning Values to Uncertain Parameters in Subsurface Contaminant Fate and Transport Modelling. National Groundwater & Contaminated Land Centre Report NC/99/38/3.

3. Environment Agency (2001) Guide to Good Practice for the Development of Conceptual Models and the Selection and Application of Mathematical Models of Contaminant Transport Processes in the Subsurface. National Groundwater & Contaminated Land Centre Report NC/99/38/2.

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5. Golder Associates (2003) The Development of LandSim 2.5. National Groundwater & Contaminated Land Centre Report GW/03/09.

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