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By email to registered users.

**WATER BALANCE AND SOURCE TERM DECLINE IN LANDSIM 2.5.17 - CLARIFICATION**

Dear LandSim User

This note provides clarification of the way water balance calculations are carried out in LandSim 2.5.17, and how the calculation of source term decline interfaces with the water balance calculations. These aspects of the tool are not described in detail in the User Manual and associated addenda, or Help files.

We have also taken this opportunity to keep you updated with two known bugs in the software which relate to the water balance (but which only occur under certain combinations of circumstances).

## LandSim as a Tool

LandSim was developed by Golder Associates (UK) Ltd. on behalf of the Environment Agency to *assist* in the assessment of risk posed to groundwater by proposed and existing landfill sites. LandSim is one of a number of available risk assessment tools, which should be selected and used appropriately. It is important to note that LandSim does not *carry out* a risk assessment – you, as the user, do that, considering your interpretation of the model output alongside other information you may have.

You should understand your conceptual site model (CSM) and be familiar with the methodology, assumptions and simplifications made within the tool that you have selected (there will always be some!). There will be cases where LandSim is inappropriate (for example sub-water table landfills, which do not fit the LandSim inbuilt fixed CSM) and you will then have to consider an alternative tool.

Further information, a demonstration version of LandSim, and a downloadable order form (which may be used to order replacement copies of the installation files or User Manual if necessary) are available on the website www.landsim.co.uk.

## Water Balance

In many ways, the water balance for a landfill is relatively simple; inflow (infiltration) must always be equal to outflow (leakage, leachate removed through pumping, and any surface breakout) and change in storage (the volume of water remaining within the waste). This simple model is assumed in LandSim, and each of these components of the water balance are presented in the results so you can check what is happening at each timestep/percentile.

Although the overall water balance is relatively simple, the factors contributing to each component add a level of complexity, and therefore more detail is provided below.

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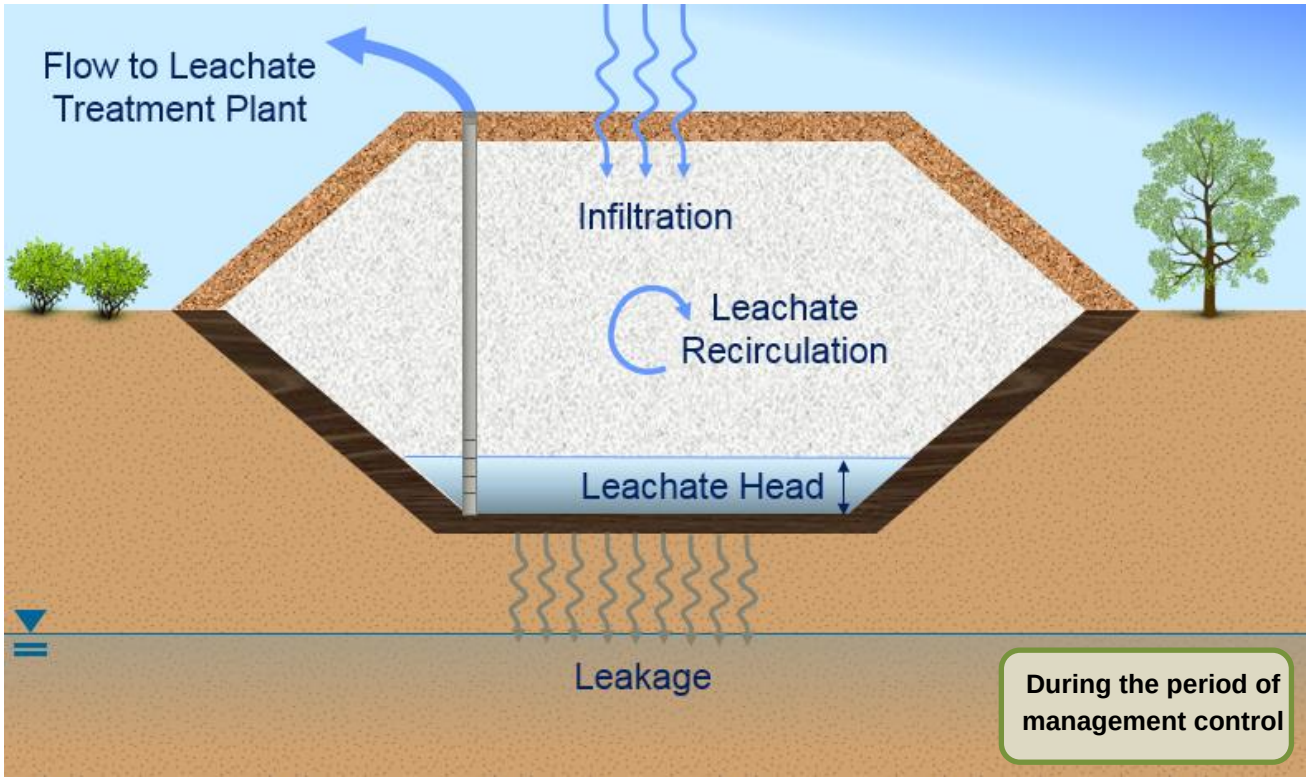
### *During Management Control*

During the period of management control, when leachate levels are actively maintained according to the site permit, the model is run using a **leachate head** which is specified by you (under the 'Drainage System' menu item). Any leachate generated in excess of this level is assumed to be pumped from each cell to the **leachate treatment plant (LTP)**. Under some circumstances, you may have specified a head that is too great for the underlying engineered barrier or unsaturated zone to sustain, and in these cases you will receive a warning on completion of the model run; you should check your input parameters and/or specify a more realistic head. In the unusual (and probably academic) situation where the head specified is higher than the surface breakout elevation, all excess water is still modelled as flowing to the LTP and there is no surface breakout flow.



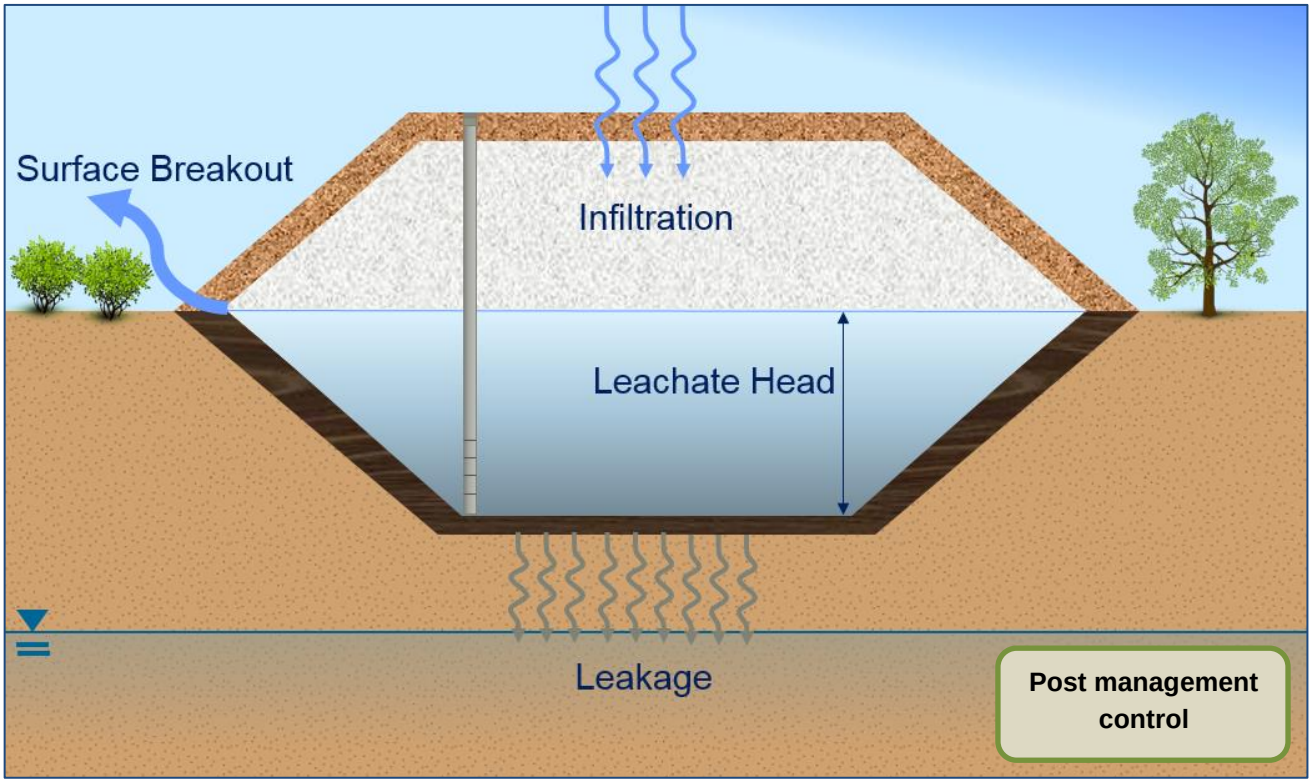

LandSim assumes that the quoted **infiltration** rate applies over the full surface area of the facility. The contribution of any other inputs (or reductions in effective infiltration) may be incorporated into the value of your infiltration estimate with explanation provided. The rate of **recirculation** of treated leachate is specified under the 'Leachate Inventory' menu because it affects the rate of contaminant concentration reduction, but it does not need to be added to your estimate of surface infiltration because the rate of leachate abstraction is assumed to be the same as the rate that it is reintroduced to the waste. Any water generated through waste degradation is assumed to be absorbed by the waste itself. It is important to note that infiltration will vary during the lifetime of the site, as the site is capped and, depending on the engineering design, as the cap degrades. Full details are provided in the User Manual and Help Files.

The magnitude of **leachate leakage** depends on the head of leachate, the characteristics of the liner system (where modelled) and the hydraulic conductivity of the underlying material. The method for calculating leakage for various liner systems is described in detail in the User Manual and LandSim Help Files. Just like the infiltration rate, the modelled rate of leachate leakage from the site may change during the site lifetime as the engineered barrier system deteriorates. The total rate of leakage through the base of the landfill cannot exceed the total rate of infiltration, so on occasions where the calculated leakage is greater than the specified infiltration

rate (for example, an unrealistically high fixed head has been specified) LandSim sets the leakage rate equal to the infiltration rate.

### *After Management Control Ends*

LandSim simulates the period after management control by setting the **flow to the LTP** and the rate of **leachate recirculation** to zero. The **leachate head** (which determines the volume of leachate held within the site) is varied according to a balance of **infiltration** and **leakage**, superseding the value you have specified. If the leakage rate always remains lower than the infiltration rate, then **surface breakout** must eventually occur. The leachate head at which surface breakout occurs is specified under the 'Cell Geometry' menu, and can be different for each landfill phase. For a land*fill*, it would typically represent the lowest edge of the void; for a land*raise* the head at the top of the perimeter bund may be used. Whatever value you select as the head at which surface breakout occurs, you should bear in mind that LandSim will not allow the calculated head to exceed this value. The volumetric rate of surface breakout will change to maintain the water balance (if, for example, infiltration continues to increase). Leachate leaving the landfill as breakout, and the potential impact of leachate breakout on the environment, are not considered further in LandSim.




Specifically, at each timestep, the volume of leachate within the cell is calculated as the volume of leachate from the previous timestep *plus* the infiltration volume for the current timestep *minus* the leakage volume from the previous timestep. The new leachate head is calculated using this new volume (equation 4, 'What's New in LandSim 2.5' User Manual insert), and a new leakage rate is calculated.

If the volume of leachate for the current timestep exceeds the maximum capacity of the cell (which is the volume assuming the leachate head is equal to the surface breakout elevation), the difference between the two is assumed to be the volume of surface breakout flow and the volume of leachate within the cell is equal to the maximum capacity.

## Declining Source Concentration

The declining source concentration calculation is described in the '*What's New in LandSim 2.5*' User Manual insert and in the Help Files (under 'Changes from Release 2 - Changes to the Source Term' and **not** under 'The Theory Behind LandSim - Declining Source').

The rate of contaminant concentration decline in the waste is based on the liquid to solid ratio (L/S), which is calculated as the sum of aqueous losses from the waste divided by the waste mass. The cumulative aqueous loss to the end of any given timestep is the aqueous loss for the previous timestep plus three different types of loss for the current time step: **leakage**, **flow to the LTP** and **surface breakout** as described above (noting that some of these may be zero). Each of these losses is ultimately dependent on the rate of infiltration to the landfill, as the only water source considered.

Remember that a high infiltration rate may result in a conservatively high rate of leakage to the geosphere, but it will also cause a faster reduction in contaminant concentration in the waste, and therefore, subsequently, in leakage.

## Known Bugs in LandSim 2.5.17

We are aware that there are bugs in LandSim 2.5.17, most of which only occur under certain, and typically unrealistic, circumstances. The following are of relevance to the water balance and declining source:

- In certain situations (e.g. when a single flexible membrane liner overlying a high permeability material is simulated), very small changes in the leachate head may result in large changes in predicted leakage and numerical instability in the model. This situation can be recognised by short frequency oscillations in the predicted leachate head over time. If this occurs, you should review the liner design to confirm whether LandSim 2.5 is appropriate. Models run with a time invariant leachate head (i.e. the duration of management control set to a value greater than or equal to 20,000 years) are not affected by this numerical instability; and

- In order to reduce computational time, LandSim will not re-calculate head and leakage at subsequent timesteps once hydraulic stability has been reached. Hydraulic stability is determined when, for example, cap and liner degradation is complete. In certain combinations of circumstances this can result in LandSim setting a steady leakage rate of 10x the infiltration rate; this can be seen in the leakage plot. The suggested workaround is to set the 'End of Cap Degradation' in the Infiltration input window to 30,000 years. If your site does not have a PE cap, check the 'PE Cap' box, set the 'End of Cap Degradation' to 30,000 years, then uncheck the 'PE Cap' box. With this workaround you will, unfortunately, still see the unrealistic leakage rate in the final timestep; you should exclude consideration of results at this timestep in your interpretation of risk.

## Other Things to be Aware of

Although the water balance model incorporated in LandSim appears simple, there are many factors which affect the ultimate concentration of contaminants at the receptor over time - infiltration changes due to cap degradation, leakage changes due to liner degradation, leachate removal rate changes due to changes in the management control period, surface breakout rate changes as part of the water balance, and changes in source concentrations related to the way these components are included in the L/S value.

The combined effect of these factors is not always intuitive (for example, you may see concentrations at the base of the unsaturated zone higher than those in the source at the same timestep), but you can usually gain a better understanding of the results of your LandSim model by considering each component of the water balance and identifying how and when you see changes. For example, does the leachate head stabilise at the elevation

you specified for surface breakout? If so, you have surface breakout occurring and you should see this reflected in the surface breakout plot.

Occasionally, you may see 'compliance point' concentrations which exceed those at the (closer) 'monitoring well'. This is likely to be a result of the method of calculating dilution in the aquifer (User Manual insert at the end of Chapter 6). Dilution at the 'monitoring well' is estimated using a mass balance which takes account of both leakage and flow in the aquifer. Calculation of dilution at the 'compliance point' assumes negligible leakage when compared with aquifer flow (necessary to allow for the combined effects of more than one landfill phase). Where, occasionally, leakage from the landfill is relatively large compared with aquifer flow, the resultant dilution calculation will be less accurate. You are likely to get a 'leachate leakage exceeded 10% of the aquifer flow' warning message alerting you to the fact.

LandSim has not been designed for Windows Vista or later. Testing was done on Windows XP and earlier operating systems during development, and whilst testing has not been completed on Windows 7 we know that it is being used extensively on Windows 7 without any reported issues. The programme does install and run apparently normally on Windows 10, but we have not verified that the results are correct, and we are aware that the Help Files are not accessible (the User Manual is the alternative source of information).

Additional information about the development of LandSim 2.5 is available in a separate report '*The Development of LandSim 2.5. National Groundwater & Contaminated Land Centre Report GW/03/09*' which was included with the installation files or may be downloaded from www.gov.uk.

If you have questions related to running and installing LandSim, please go to the 'Frequently Asked Questions' section of the website www.landsim.co.uk or contact the Help Desk on **uklandsim@golder.com** and we will be pleased to assist.