Evaluating landfill aftercare strategies: a life-cycle assessment approach

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David Turner

Co-authors:
Richard Beaven & Nick Woodman, University of Southampton
Introduction
Landfill Aftercare – key issues

- Landfills have a significant pollution potential & may contribute to a range of environmental impacts\(^1\)

- Typical landfill management leads to aftercare timescales of 100s - 1000s years before FSQ\(^2,3\)

- Unresolved post-landfill closure issues:
  - Uncertain funding\(^4\)
  - Possible **loss of active control systems** for a period of time
  - Burden & impact on future generations

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1 Christensen *et al.*, 2011
2 Knox, 1990
3 Knox *et al.*, 2005
4 Beaven *et al.*, 2014
Introduction

Life cycle assessment (LCA)

- Well-established, standardised methodology (ISO 14040 & 14044)
- Accounts for all resource use & emissions during complete life cycle
- Aggregates emissions into impact categories
- Impacts can be normalised to person equivalents (PE)

Source: Manfredi & Christensen (2009)
Introduction
Life cycle assessment (LCA)

- LCA has been extensively applied to evaluate landfill e.g. 1,2,3

- Most previous LCA studies of landfills use 100 year timeframe e.g. 1,4,5

- Existing LCA tools (e.g. WRATE & EASETECH) unsuitable for modelling the effect of active control loss on landfill impacts

- No previous LCA studies to evaluate the effect of active control loss on the overall impacts of landfilling

1 Damgaard et al., 2011  
2 Xing et al., 2013  
3 Turner et al., 2016  
4 Manfredi & Christensen, 2009  
5 Manfredi et al., 2010
Introduction

Goal & scope of the work

Goal
To evaluate the potential impacts of leachate emissions from landfill sites operated with different aftercare strategies, taking into account the effects of potential active control loss

Purpose
1. To investigate whether LCA can be used to improve our understanding of the long term impacts of landfilling
2. To develop understanding of potential impact of active control loss

Scope (‘functional unit’)
- Leachate emissions over a 10,000 year time horizon
- Completed non-hazardous MSW landfill site of 10,000 m² x 20 m
Method

Integrated solute flow model & LCA approach

Schematic of integrated solute flow model and LCA approach

Impact categories:
HTc, carcinogenic human toxicity; HTnc, non-carcinogenic human toxicity; ET, ecotoxicity;
EUF, freshwater eutrophication; EUm, marine eutrophication
Method

Mechanistic water flow & solute movement model

Schematic of the mechanistic model under conditions of:

a) active control (i.e. leachate collected for treatment)

b) active control loss (i.e. leachate not collected for treatment) & where $Q_i > Q_g$ → overtopping
Method

Integrated solute flow model & LCA approach

Impact categories:
HTc, carcinogenic human toxicity; HTnc, non-carcinogenic human toxicity; ET, ecotoxicity;
EUf, freshwater eutrophication; EUm, marine eutrophication
### Method

#### Aftercare scenarios

**Description of landfill aftercare scenarios**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>S1 Typical aftercare</td>
<td>High quality, low permeability cap</td>
</tr>
<tr>
<td>S2 Accelerated aftercare (high permeability cap)</td>
<td>High permeability cap</td>
</tr>
<tr>
<td>S3 Accelerated aftercare (30 year moisture injection)</td>
<td>High permeability cap; additional moisture injection during 30 year active aftercare operations period</td>
</tr>
<tr>
<td>S4 Accelerated aftercare (60 year moisture injection)</td>
<td>High permeability cap; additional moisture injection during 60 year active aftercare operations period</td>
</tr>
</tbody>
</table>

**Model input parameter values assigned for each aftercare scenario**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
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<tbody>
<tr>
<td>Design flow through cap</td>
<td>mm/a</td>
<td>50</td>
<td>250</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td>Flow through cap at end of ‘active aftercare period’</td>
<td>mm/a</td>
<td>60</td>
<td>250</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td>Flow after cap has reached end of service life</td>
<td>mm/a</td>
<td>250</td>
<td>250</td>
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<tr>
<td>Time at end of ‘active aftercare operations period’</td>
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<td>30</td>
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<td>30</td>
<td>60</td>
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<td>30</td>
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<td>60</td>
</tr>
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Results

Solute flows by pathway & scenario

S1 Typical aftercare

Mass via treatment

Mass via groundwater

Mass via surface water

‘best case’

‘worst case’

S2 Accelerated aftercare (high permeability cap)

Mass via treatment

Mass via groundwater

Mass via surface water

$T_F =$ time at which leachate no longer removed to treatment

$D =$ duration of period where leachate not removed
Results

Solute flows by pathway & scenario

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S2 Accelerated aftercare (high permeability cap)

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Solute flows by pathway & scenario

S3 Accelerated aftercare (30 year moisture addition)

S4 Accelerated aftercare (60 year moisture addition)

$T_F =$ time at which leachate no longer removed to treatment

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Solute flows by pathway & scenario

$S_1$ Typical aftercare

- Mass via treatment
- Mass via groundwater
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$S_2$ Accelerated aftercare (high permeability cap)

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- Mass via groundwater
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Solute flows by pathway & scenario

S3 Accelerated aftercare (30 year moisture addition)

Mass via treatment

Mass via groundwater

Mass via surface water

S4 Accelerated aftercare (60 year moisture addition)

Mass via treatment

Mass via groundwater

Mass via surface water

$T_F =$ time at which leachate no longer removed to treatment

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Results
Total normalised potential impacts by pathway & scenario

S1 Typical aftercare

Mass via treatment

Mass via groundwater

Mass via surface water

Total

S2 Accelerated aftercare (high permeability cap)

Mass via treatment

Mass via groundwater

Mass via surface water

Total

$T_F = \text{time at which leachate no longer removed to treatment}$

$D = \text{duration of period where leachate not removed}$

$\text{PE} = \text{person equivalents}$
Results

Total normalised potential impacts by pathway & scenario

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**Total normalised potential impacts by pathway & scenario**

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PE = person equivalents
## Results

### Comparison of scenarios

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<tr>
<th>Scenario Description</th>
<th>‘Best case’ (PE)</th>
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<td>0.060</td>
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<td>0.14</td>
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<td>Ecotoxicity</td>
<td>4,390</td>
<td>0.027</td>
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<td>Marine eutrophication</td>
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<td>6,760</td>
<td>0.042</td>
<td>20,050</td>
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<td>(high permeability cap)</td>
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<td>6,400</td>
<td>0.040</td>
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* person equivalents
## Results

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## Results

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* person equivalents
# Results

## Comparison of scenarios

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\( \text{PE}^a \) person equivalents
Discussion

The use of LCA to evaluate aftercare strategies

- Platform to compare and contrast different aftercare strategies

- LCA can provide a more complete indication of the environmental performance of a site

- BUT life cycle impact assessment purely mass based
  - Potential impacts of a fully controlled landfill only ~3 times better than those of a landfill with no active controls (!)

- Lack of toxicity-related characterisation factors
Conclusions

Key findings

- 100 y timeframe insufficient to evaluate impacts of landfilling
- Active control loss found to significantly influence the long-term potential impacts of landfilling
- Largest potential impacts in both the ‘best case’ and ‘worst case’ resulted from the typical aftercare scenario
- Need for more sophisticated life cycle impact assessment
Acknowledgements

- Research undertaken at the University of Southampton
- Financial support provided by EPSRC
- Thanks to Keith Knox & Kerry Rowe for input into the methodology and to Jan Gronow & Terry Coleman for feedback on the paper

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