AFTERCARE OF LANDFILLS
OVERVIEW OF TRADITIONAL AND NEW TECHNOLOGIES

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SUMMARY: *Based upon a rough estimation Europe counts more than 150.000 landfills. It is a mixture of old and abandoned landfills, recently closed landfills and landfills still in operation. The operational and recently closed landfills should meet the the operational and technical requirements of the EU-directive on the landfilling of waste (1999/31/EC). Old and abandoned landfills arenot included in this EU-directive. These landfills do not have any type of bottom liner system and for that reason only it will not be possible to meet the EU-requirements anyway. So these landfills must be seen as earlier cases of pollution, which must meet the requirements of national legislation and rules with respect to the clean up of contaminated sites. The main starting point is that application of aftercare-measures is only necessary to eliminate actual risks as well as to avoid future risks to human health and the environment, due to the presence of the landfill site. As a general principle it can be stated that the higher the risk, the more serious the after-care measure. An overview of traditional aftercare measures is given as well as insight in new technologies based on the phenomenon of Natural Attenuation (self cleaning ability of nature) and waste mining. Financial figures are presented with respect to the costs of aftercare. Finally the costs of the traditional aftercare will be compared to the costs of aftercare based upon Natural Attenuation.*

1. INTRODUCTION

Based upon a rough estimation, Europe counts more than 150.000 landfills. These landfills can be divided into the following three categories:

1. operational landfills.
2. recently closed landfills.
3. old and abandond landfills.

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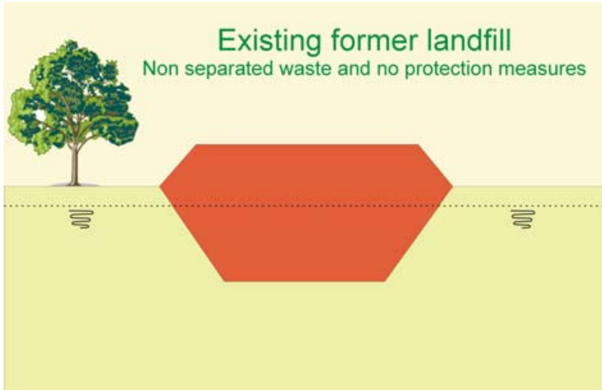

The first two categories should meet the operational and technical requirements with respect to aftercare of the EU-directive on the landfilling of waste (1999/31/EC). The third category is not included in this EU-directive. These landfills have been exploited and closed decades ago, contains all types of waste (non separated waste) and do not have any type of aftercare measure, such as for example bottom liners (figure 1). This means that these landfills are not or insufficiently provided with appropriate measures and facilities to protect its environment (soil, groundwater, air) from contamination. The quality of soil and groundwater can be affected due to leaching of contaminants from the waste material, and air pollution can be caused by emission of biogas (carbondioxide and methane).

ned landfill

The main questions with respect to aftercare are:

- What kind of aftercare meaures can be taken to eliminate or reduce negative environmental effects?
- What are the costs of these aftercare measures?

2. RISK APPROACH

The main starting point is that application of aftercare-measures is only necessary to eliminate actual risks as well as to avoid future risks to human health and the environment , due to the presence of the landfill site. As a general principle it can be stated that the higher the risk, the more serious the after-care measure.

The old and abandoned landfill is more or less considered a ‘black box’ with respect to the types of waste which have been stored. During the operational period of the landfill, the volume and the acceptance of waste was not administrated in those days. For that reason the emphasis is laid on migration risks, i.e. spreading of contaminants to the four environmental elements groundwater, surfacewater and air as well as direct contact with the waste by human beings, animals and crops (figure 2). From this approach, the following four risk components are distinguished:

1. **Landfill gas**: related to direct exposure of human beings, cattle and vegetation to emitted biogas;
2. **Surface-water**: related to the spread of pollutants to surface-water, resulting in the potential risks of the use of polluted surface-water by human beings (swimming), by cattle (drinking) and for agricultural purposes (irrigation);
3. **Groundwater**: related to the emission of pollutants from the landfill to soil and groundwater and resulting in the potential risks of using polluted groundwater by human beings (drinking water), by cattle (drinking), for agricultural purposes (irrigation), as well as damage to vegetation and the groundwater supply in general;
4. **Landfill coverage**: related to direct exposure to the waste materials, resulting in risks to human health by means of direct contact, consumption of crops cultivated at the landfill and consumption of meat from livestock grazing at the landfill.

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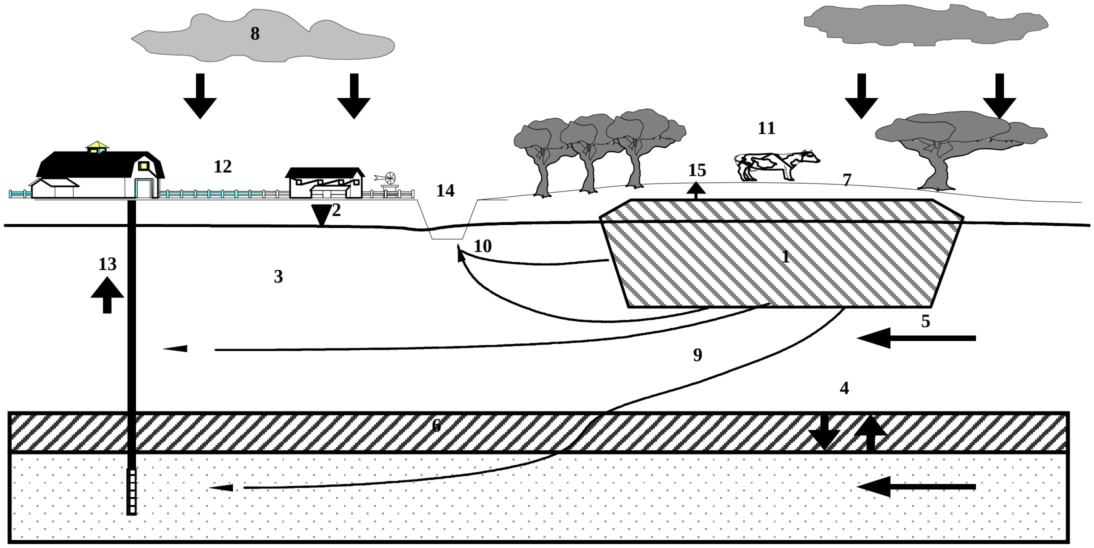


1: landfill
2: groundwater level
3: phreatic grounwater
4: seepage / infiltration
5: natural groundwaterflow
6: impermeable layer
7: landfill cover
8: deposition
9: spread by groundwater
10: spread by surface water
11: use of landfill
12: use of environment
13: use of groundwater
14: use of surface water
15: landfill gas

Figure 2 The environment of a landfill (emission, migration and impact)

3. AFTERCARE MEASURES

3.1 General categories of aftercare actions

Based upon the risk approach, all landfills can be classified into risk categories. At the other hand the also the aftercare actions can be classified into categories. Table 1 shows the relation between risk and aftercare categories.

Table 1 Risk-scores related to categories of aftercare-actions

Risk categories		Categories of aftercare-action			
		Goundwater-monitoring	Containment	Remediation or Restrictions	Recultivation (coverage layer)
A	no/less risk	X	-.-	-.-	X
B	moderate risk	X	-.-	-.-	X
C	high risk	X	X	-.-	X
D	very high risk	X	-.-	X	X

Groundwater-monitoring as well as recultivation (top liner, coverage layer) has been indicated for all landfills. Groundwater-monitoring is always necessary as a first step in order to verify the absence or presence of groundwater contamination. It can be seen as the necessary verification step from potential risk to actual risk. Recultivation has to be applied to all landfills, because at almost all old and abandoned landfills a proper landfill coverage layer is missing.

3.2 Types of aftercare actions

All main categories can be divided into various types of aftercare-actions. Table 2 shows the various aftercare actions related to the four risk-components landfill gas, surface water, landfill coverage and groundwater.

Table 2 Overview aftercare actions related to risk components

Aftercare actions	**Applicabiliy to risk component**			
	Landfill gas	Surface water	Landfill coverage	Ground-water
Monitoring				
Traditional sampling & analyses (absence/presence actual risks)				
NA-sampling & analyses (also absence/presence future risks)				
Sampling and analysis				
Containment				
Extraction and treatment of contaminated groundwater in order to avoid further spread of the actual polluted groundwaterplume.				
Construction of vertical impermeable screens				
Impermeable top liner to avoid infiltration of water				
Soil cover to avoid exposure to waste				
Passive extraction and combustion of landfill gas				
NA-monitoring (MNA) to verify the stand-still or shrinkage of the polluted groundwaterplume				
Remediation				
Excavation of waste (waste mining)				
Active extraction and combustion of landfill gas				
Oxidation coverage layer (Natural Attenuation)				
Extraction and treatment of contaminated groundwater in order to eliminate the actual polluted groundwaterplume.				
NA-monitoring (MNA) to verify the shrinkage and final elimination of the polluted groundwaterplume				
Restrictions				
access to landfill site limited or forbidden by means of placing boards and or fences around the landfill site.				
use of surfacewater is limited/forbidden by means of placing boards.				
Recultivation				
Improvement of the surface of the landfill by a proper coverage layer (in combination with natural landfill gas oxidation).				
Fitting in the landfill into the landscape in tune with the use of the surrounding area.				
Redevelopment the landfill area, in tune with the redevelopment plans of the municipality.				

3.3 The impact of Natural Attenuation

Natural Attenuation (NA) is comprised of all natural processes in both the landfill body and the soil downstream from the landfill, such as the microbiological decay of organic compounds, the chemical precipitation of heavy metals and the sorption of contaminants to organic material and silt particles. NA is taking care of the reduction and/or elimination of contaminants. As a result of NA few contaminants leave the landfill, and the wide range of redox-conditions down-gradient from the landfill (from methanogenic to nitrate-reducing/oxic) nearly always contains specific boundary conditions necessary for biotransformation and precipitation of contaminants.

A prerequisite for the occurrence of NA is the presence of organic matter. The disposed waste in the landfill always contains a certain percentage of organic matter. The amount of organic matter in a landfill depends on the type of waste. Domestic waste contains a much higher percentage of organic matter than construction and demolition waste, for instance.

Organic matter initiates decomposition processes in the landfill. These processes influence the (macro)chemical composition of the leachate produced by the landfill. The decomposition process results in changes in the chemical composition of the landfill leachate (water-types) as the disposed waste grows older. Generally, the aerobic conditions at the start of operations of the landfill will change into anaerobic conditions after a period of approximately 10-20 years. At the end of this period, the anaerobic conditions at the landfill will remain more or less steady (final storage quality).

The chemical composition of landfill leachate corresponds to redox conditions to a certain extent, and, therefore, to the type and extent of NA at that particular landfill. From the start of operations of the landfill, the redox conditions in the landfill change during this period of 10-20 years as per the following sequence: (sub)oxic - nitrate reducing - iron reducing - sulphate reducing - methanogenic/anoxic.

If there are no protection measures to soil and groundwater downstream from the landfill, a leachate-plume will be developed. This leachate-plume will affect the chemical quality of the groundwater and is the transition zone between the chemical composition of the leachate in the landfill directly beneath the landfill and the existing chemical quality of the natural groundwater at a certain distance downstream the landfill. This means that a sequence of redox conditions and therefore NA processes are also to be found in the leachate-plume.

The advantages of the implementation of NA in the strategy of aftercare can be summarised by means of the following core notions:

- the landfill is considered to be a biochemical reactor in stead of a “chemical time-bomb”;
- no or very limited environmental risks with respect to emission of contaminants to the groundwater, which means less financial risks with respect to aftercare;
- from everlasting aftercare to ending aftercare, which leads to lower aftercare costs.
- at the long term the landfill will become harmless and from a social point of view it will not cause a problem anymore to our next generations (sustainable landfilling).
- redevelopment of the landfill site is possible at an earlier stage.

A comparison between traditional aftercare and NA-aftercare is resulting in the following picture as presented in table 3.

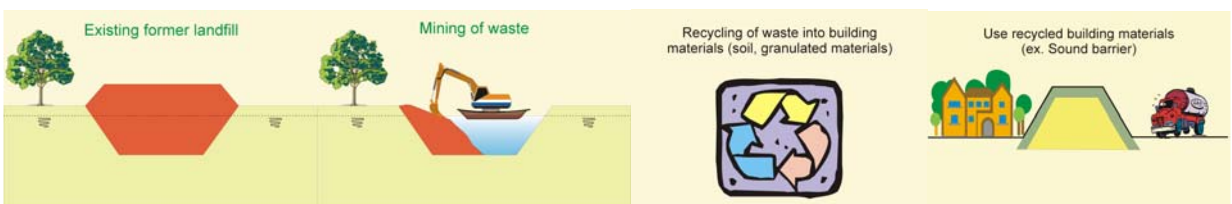
Table 3 Comparison traditional aftercare and NA-aftercare

Traditional aftercare	NA-aftercare
Black box	Grey or white box
Future risks unknown	Future risks known
Long monitoring period	Short monitoring period
Monitoring with high frequency	Monitoring with low frequency
Remedial and containment actions	Intensive NA-monitoring
Expert judgement	Specialistic expertise
Expensive	Less expensive

3.4 Waste mining

One of the aftercare-measures of the old and abandoned landfills can be the excavation of the landfilled waste and recycling the excavated waste into building materials (waste mining). Because of the landfilling of non separated waste in these old landfills, the landfill contains all kinds of recyclable waste, such as demolition waste (granules), domestic waste (compost), soil (sand).

The use of these recycled building materials results in economical benefits (it replaces the expensive natural raw materials), which lowers the costs of aftercares in case of excavation osen as a aftercare action).



4. THE COSTS OF AFTERCARE

To get an realistic impression of the costs of aftercare of old and abandoned landfills, table 4 shows the Hungarian situation as an example. It concerns the costs of aftercare of 2667 landfills which has been calculated by Royal Hakoning in the framework of the establishment of a masterplan aftercare for the Hungarian Ministry and financed by the European Union. The costs af traditional aftercare as well as the costs of NA-aftercare are presented.

Table 4 Costs of aftercare (Hungarian situation as an example) in million of €

	Traditional aftercare	NA-aftercare	Savings
Landfill gas	462	246	47%
Coverage layer	229	229	0%
Surface water	13	13	0%
Groundwater	515	94	82%
Total in €	1.219	582	52%

Comparison between the tradional aftercare and NA-aftercare shows that the application of NA as a aftercare option lowers the costs by 50%. This cost saving only concerns the risk components landfill gas and groundwater. These risk components are aslo dominating the total aftercare costs (80%).

In order to validate these aftercare costs, the Hungarian aftercare costs have been compared to the total aftercare costs for the 3.800 old and abandoned landfills in the Netherlands (only for the aftecare costs for groundwater and landfill).

	Total costs (€)	**Number of landfills**	**Average per landfill**
Hungary (calculated)	€ 744 x 10^6	2.667	€ 279.000
Netherlands (calculated)	€ 1.045 x 10^6	3.800	€ 280.000
Europe (estimation by extrapolation)	**€ 42.000 x 10^6**	150.000	

5. STATEMENT

The total costs of traditional aftercare of all landfills in Europe is roughly valued at € 40.000 to 50.000 million (€ 40-50 billion). This is a hugh amount of money, which can hardly be financed from public environmental budgets only. Application of new aftercare technologies such as Natural Attenuation will lower the aftercare costs by approximately 50%.

Already in several countries (a.o. Netherlands, UK) the public authorities are aware of the positive effects of Natural Attenuation in an environmental as well as in a financial way. This means recognition that NA can be the key to a sustainable, feasible and affordable aftercare of landfills.