

# EXAMINATION ON LANDFILLS

## EUROPEAN METHODOLOGY FOR SURVEY, INVENTORY AND CLASSIFICATION OF LANDFILLS

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**SUMMARY:** *Within the framework of a strategic plan for managing municipal waste, the Hungarian ministry of environment issued the project “Investigations on Municipal Solid waste Landfills”, financed by the European PHARE country program. The project consisted of the specification and application of a methodology for the survey, inventory and environmental ranking of the 2667 landfills. Besides, a chemical investigation at 139 selected landfills has been executed in order to validate the calculated environmental risks by means of the methodology as well as to show the occurrence of Natural Attenuation (NA). The results shows that landfill gas to be produced and the absence of an appropriate coverage layer can be considered as the major environmental issues. At the other hand groundwater and surfacewater are the minor environmental issues. The potential environmental risks resulting from the methodology corresponds more than sufficient to the results from the chemical field investigations. So it can be conclude that a validated and calibrated methodology has been developed, taking into account all available European expertise as well as the phenomenon of Natural Attenuation, which is unique in the European context.*

### 1. INTRODUCTION

Based upon a rough estimation, Europe counts more than 150.000 former and abandoned landfills, which do not or partly meet the operational and technical requirements of the EU-directive in the landfilling of waste (1999/31/EC). 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 (methane and carbondioxide).

In August 2001 the European Union financially assisted the Hungarian Ministry of Hungary to investigate the 2667 Hungarian landfills within the framework of PHARE Country Program. According to the Terms of Reference, the project has been divided into two main components:

1. Specification of a methodology for the survey, inventory and environmental classification of the 2667 landfills, based upon available European expertise;
2. Application of the specified methodology for survey of the 2667 landfills.

This paper is focussed on the key-elements in the specified methodology, which are :

- the integration of **"European expertise"** from EU-countries by means of inventory and selection of relevant methodologies in other European countries.
- the introduction and integration of the phenomenon of **"Natural Attenuation"** (for the first time in European context);
- the **elaboration** and **validation** of the environmental risk-scores of landfills and the occurrence of Natural Attenuation at landfills by means of chemical analyses at 139 landfills.
- the **results** of the applied methodology at 2667 landfills with respect to environmental ranking and measures to be taken;

## 2. THE OBJECTIVES

The main objectives of the project can be formulated as follows:

- to obtain a specified methodology, based upon the results of a validation process.
- to obtain an environmental ranking of the landfills based upon the applied methodology. .
- to present a categorisation, based upon the environmental situation.

## 3. THE METHODOLOGY

### 3.1 The basic concept

The main objective of the methodology is to determine the potential risk of each individual landfill site with respect to its adjacent environment, i.e. the methodology can be considered as technical risk assessment on local scale.

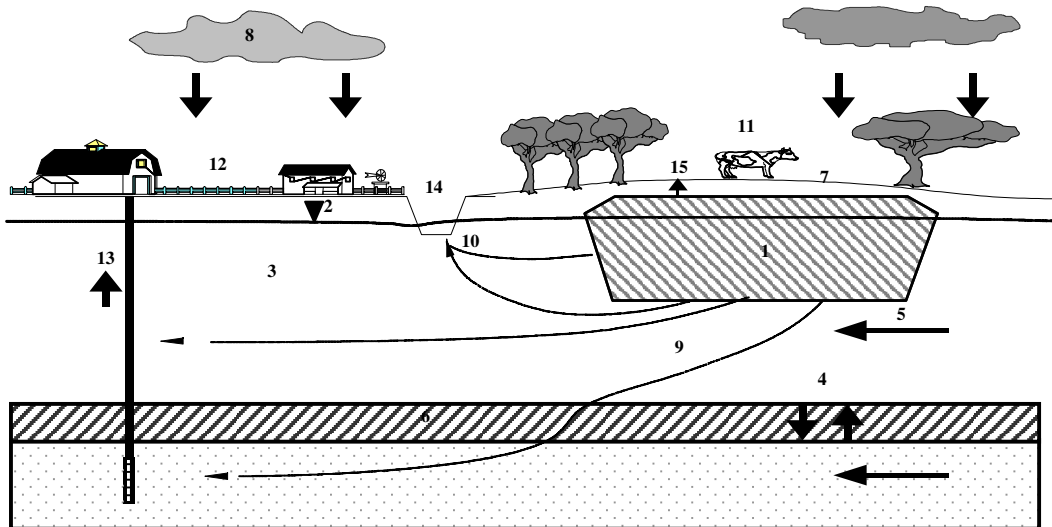
An analysis of the inventory of existing relevant methodologies in Europe, shows that all methodologies apply the source-pathway-receptor approach. As the environmental risks caused by the presence of landfills in Hungary are comparable to the other European countries, this approach can also be applied in the Hungarian situation.

The landfill is considered a black box, where 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 1). From this approach, the following four risk components are distinguished in the basic concept:

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.



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

Figure 1 The environment of a landfill (emission, migration and impact)

### 3.2 The role 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.

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.

### 3.3 Application of the methodology

Applying the risk-assessment methodology, results in the following risk-components:

- **Intrinsic Risk Score (IRS);** The assessment of the potential risks of the landfill (source-pathway-receptor) without taking into account any risk-reduction due to any protection measures present. The IRS gives insight in the maximum risks of the landfill and can be considered as the worst-case scenario.
- **Risk-reducing factor (RR-factor);** Measures such as bottom liners to avoid emission of contaminants from the landfill to groundwater, landfill gas collection systems, leachate collection systems, etc. Any risk-reducing measure found at the site will be inventoried separately and will be considered as a reduction of the intrinsic potential risk.
- **Final Risk Score (FRS);** The final risk score for each risk component will be determined by multiplying the intrinsic risk score (IRS) and the artificial risk-reducing factor (RR-factor). The final risk score for the landfill site is determined by adding and weighing the 4 final risk scores of each risk component.
- **NA-Score (NAS);** Due to the presence of organic matter, natural attenuation (NA) is occurring in and downstream each landfill at any time. Therefore, the landfill can be considered a dynamic biochemical reactor, in which NA reduces and, in the long-term, even eliminates unacceptable concentrations of contaminants. In practice, the occurrence of NA can be estimated by scoring relevant parameters (age of the landfill, % organic matter in waste and in soil, level of humidity in waste, etc.) and can be proved by means of Monitoring the Natural Attenuation processes (MNA) in and downstream the landfill. When the measured NA-conditions are favourable, MNA can be considered:
  - a cost-effective aftercare measure if contamination is already present, which can replace the relatively expensive remedial measures (abstraction of contaminated groundwater, purification of abstracted contaminated groundwater, etc.); and
  - a cost-effective prevention measure by steering and controlling NA-processes in the landfill body in order to eliminate contaminants and to avoid future emission of contaminants from the landfill.

Figure 3 shows the process of calculation the risk scores of the “European methodology”.

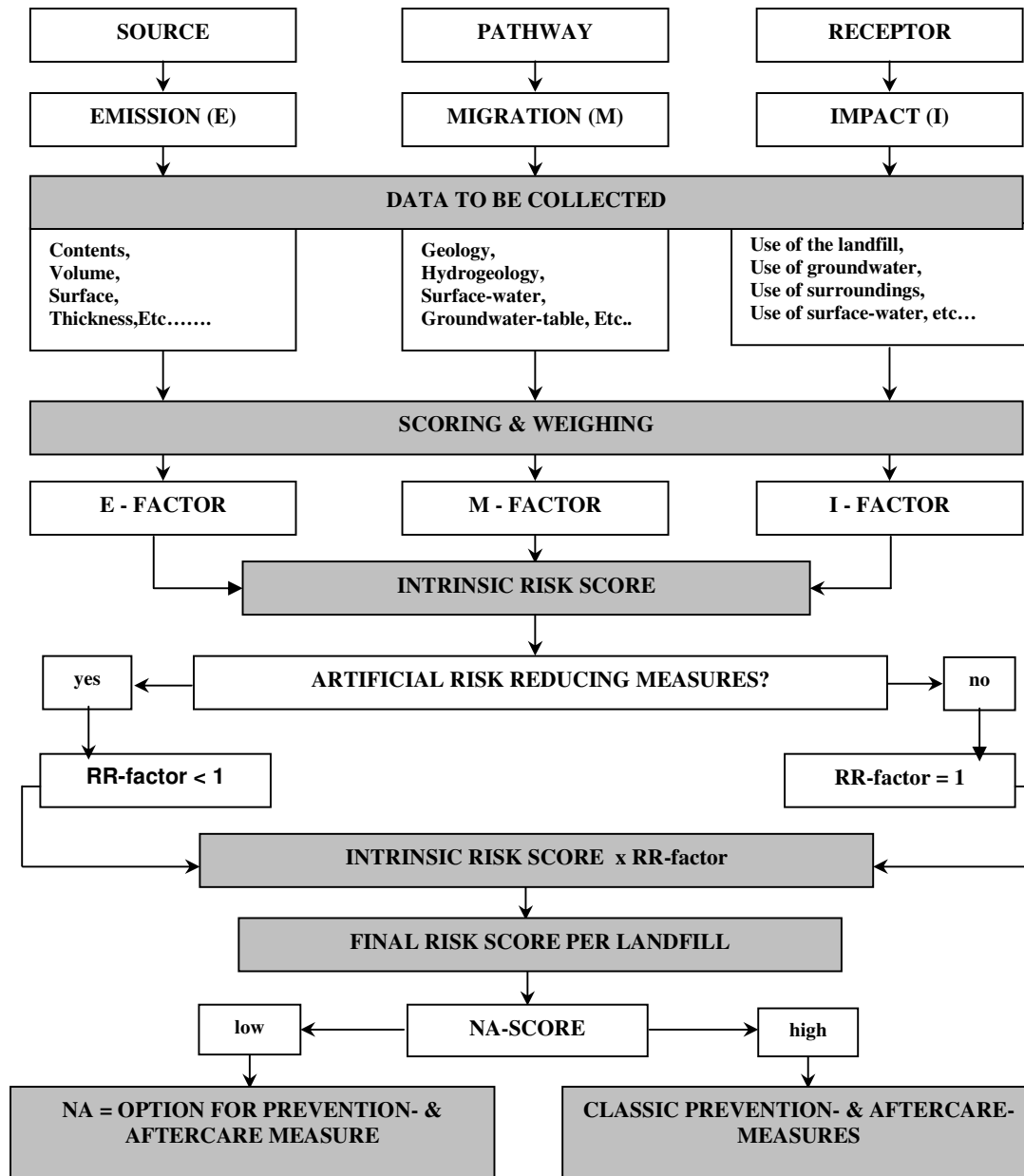


Figure 3. Flowchart of the “European methodology”

### 3.4 Calculation of the risk-scores

The risk-assessment consists of the calculation of the 3 main components, as listed below:

- Determination of the Intrinsic Risk Score (IRS)
- Determination of the artificial risk-reducing score (RR-factor)
- Determination of the risk-reduction due to natural processes (NA-score)

Table 1 shows the calculation matrix of the risk-scores. The calculation of these 3 main components is based upon a large number of criteria and data, which are related to each of the 12 individual cells A1 up to C4 (table 1). In total 32 criteria have been inventoried and listed. As an example table 2 shows the used criteria for the calculation cell A3 and the NA-factor.

Table 1. Calculation of the intrinsic risk score and final risk score

Risk components	E-factor	M-factor	I-factor	IRS	RR-factor	FRS
Landfill gas	A1	B1	C1	IRS <sub>1</sub> f(A <sub>1</sub> ,B <sub>1</sub> ,C <sub>1</sub> ,W <sub>E</sub> ,W <sub>M</sub> ,W <sub>I</sub> )	RR <sub>1</sub>	FRS <sub>1</sub> = IRS <sub>1</sub> * RR <sub>1</sub>
Surface-water	A2	B2	C2	IRS <sub>2</sub> f(A <sub>2</sub> ,B <sub>2</sub> ,C <sub>2</sub> ,W <sub>E</sub> ,W <sub>M</sub> ,W <sub>I</sub> )	RR <sub>2</sub>	FRS <sub>2</sub> = IRS <sub>2</sub> * RR <sub>2</sub>
Groundwater	A3	B3	C3	IRS <sub>3</sub> f(A <sub>3</sub> ,B <sub>3</sub> ,C <sub>3</sub> ,W <sub>E</sub> ,W <sub>M</sub> ,W <sub>I</sub> )	RR <sub>3</sub>	FRS <sub>3</sub> = IRS <sub>3</sub> * RR <sub>3</sub>
Landfill coverage	A4	B4	C4	IRS <sub>4</sub> f(A <sub>4</sub> ,B <sub>4</sub> ,C <sub>4</sub> ,W <sub>E</sub> ,W <sub>M</sub> ,W <sub>I</sub> )	RR <sub>4</sub>	FRS <sub>4</sub> = IRS <sub>4</sub> * RR <sub>4</sub>
<b>Total risk score per landfill:</b> IRS <sub>total</sub> , FRS <sub>total</sub>				IRS <sub>total</sub> = f(IRS <sub>i</sub> ,W <sub>i</sub> )  I = 1,2,3,4		FRS <sub>total</sub> = f(FRS <sub>i</sub> ,W <sub>i</sub> )  I = 1,2,3,4

W<sub>E</sub> = weight Emission factor  
W<sub>M</sub> = weight Migration factor  
W<sub>I</sub> = weight Impact factor

W<sub>1</sub> = weight landfill gas  
W<sub>2</sub> = weight surface-water  
W<sub>3</sub> = weight groundwater  
W<sub>4</sub> = weight landfill coverage

The scores of the emission-factor, migration-factor and impact-factor for all 4 risk-components landfill gas, surfacewater, groundwater and landfill coverage are calculated by scoring the criteria, multiplying the criteria by their weighing factor (table 2). All resulting risk-scores are normalised on a scale from 0 up to 10.

## 4. RISK SCORES AND ENVIRONMENTAL RANKING

### 4.1 First impression

Applying the methodology is resulting in calculated risk-scores. The risk-scores have been calculated for all 2667 in Hungary . As a first general impression a overview of the calculated risk-scores is presented in table 3.

## 4.2 Landfill gas

From table 3 it can be derived that landfill gas in general can be seen as a major problem. Approximately 97% of the landfills (2584) is scoring an IRS > 5. Besides almost 100% of the landfills is scoring a migration factor > 7,5, which means that landfill gas can emit due to the lack of a coverage layer or a coverage layer of sufficient thickness.

## 4.3 Surface-water

From table 3 it can be derived that surface-water in general can be seen as a minor problem. Approximately 79% of the landfills (2116) is scoring in the low risk-categories and only 21% of the landfills (551) is scoring risk-scores > 5.

## 4.4 Groundwater

From table 3 it can be derived that groundwater in general can be seen as a relative small problem. Approximately 65% of the landfills (1746) is scoring in the low risk-categories (risk-scores < 5) and only 0,3% of the landfills (9) is scoring in the highest risk-category (risk-scores > 7,5).

Table 2 - Example of used criteria for the calculation of cell A3 and the NA-factor

Criteria	Scores (S)*				
	1	2	3	4	5
Cell A3					
Thickness waste in groundwater [%]	0	0 < T < 25	25 < T < 50	50 < T < 75	75 < T < 100
Age of landfill [year]	age > 30	30 ≥ age > 20	20 ≥ age > 10	10 ≥ age > 2	age ≤ 2
Volume of the landfill [m3x1000]	0 < V ≤ 5	5 < V ≤ 25	25 < V ≤ 100	100 < V ≤ 500	V > 500
Area of landfill [m2]	0 < LA ≤ 0,1	0,1 < LA ≤ 0,5	0,5 < LA ≤ 2,5	2,5 < LA ≤ 10	LA > 10

\* 1 = low risk, 5 = high risk

NA-factor**	5	4	3	2	1
Age landfill (i.e. age disposed waste)	age ≤ 2	10 ≥ age > 2	20 ≥ age > 10	30 ≥ age > 20	age > 30
% domestic waste (organic matter)	0 < DW ≤ 20	20 < DW ≤ 40	40 < DW ≤ 60	60 < DW ≤ 80	DW > 80
Type of geological cover layer	gravel	sand		silt	clay
Annual precipitation	AP ≤ 550	550 < AP ≤ 600	600 < AP ≤ 650	650 < AP ≤ 725	AP > 725
waste water/sludge disposed?	w = 0%	0% < w ≤ 10%	10% < w ≤ 25%	25% < w ≤ 50%	w > 50%
Type of landfill coverage	plastic and soil	plastic	clay	thick earth layer	thin earth layer, none

\*\* 1 = favourable, high NA-potential, 5 = unfavourable, low NA-potential

## 4.5 Landfill coverage

From table 3 it can be derived that the lack of landfill coverages in general can be seen as a major issue. Almost 100% of the landfills is scoring in the high risk-categories (migration-factor risk-score > 5), which means no cover layer or cover layer with insufficient thickness. With respect to the impact-factor, 42% of the landfills (1110) is scoring in the high risk-categories (risk-scores > 5), which means action on the short term to eliminate inadmissible risks to human health and environment.

Table 3 - General distribution of the risk-scores versus numbers of landfills.

Type of risk-score	Categories of risk-scores*									
	low risk ←					→ high risk				
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
IRS <sub>total</sub>	0	0	18	624	1164	742	118	2	0	0
IRS1: landfill gas	0	0	2	2	79	529	1122	857	72	5
IRS2: surface water	0	10	444	1250	414	332	182	35	1	0
IRS3: groundwater	0	0	34	515	1217	671	190	38	3	0
IRS4: landfill coverage	0	0	1	2	4	52	699	1680	165	65
<b>Landfill gas (IRS1)</b>										
Emission A <sub>1</sub>	0	8	49	213	392	677	843	373	94	19
Migration B <sub>1</sub>	4	0	1	0	10	0	0	477	0	2176
Impact C <sub>1</sub>	33	262	115	1086	74	862	48	7	35	146
<b>Surface water (IRS2)</b>										
Emission A <sub>2</sub>	0	0	2	32	147	625	1100	505	207	50
Migration B <sub>2</sub>	72	227	493	886	607	230	105	48	0	0
Impact C <sub>2</sub>	2001	102	0	0	34	2	177	261	68	23
<b>Groundwater (IRS3)</b>										
Emission A <sub>3</sub>	0	0	2	32	147	625	1100	505	207	50
Migration B <sub>3</sub>	81	447	549	636	356	150	379	70	0	0
Impact C <sub>3</sub>	0	614	95	673	1070	1	49	8	55	103
<b>Landfill coverage (IRS4)</b>										
Emission A <sub>4</sub>	0	0	0	0	0	47	144	1318	900	259
Migration B <sub>4</sub>	4	0	1	0	10	0	0	477	0	2176
Impact C <sub>4</sub>	48	141	271	917	181	845	70	1	29	165

\* categories are up to and including last number, i.e. for example 0 up to and including 1

## 4.6 Natural Attenuation

The distribution of the NA-scores versus numbers of landfills is presented in table 4. From table 4 it can be derived that more than 75% of the landfills is scoring in the favourable categories (< 5). This means that favourable conditions are present to reduce and/or even eliminate the concentrations of hazardous microcontaminants.

Table 4 : General distribution of the NA-Score (NAS) versus numbers of landfills.

Type of risk-score	Categories of NA-scores*									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
	favourable ←					→ unfavourable				
NA-score	0	0	32	609	1367	576	77	4	2	1

\* categories are up to and including last number, i.e. for example 0 up to and including 1

## 5. VALIDATION OF RISK SCORES AND NA-SCORES

### 5.1 Risk-scores and concentration levels

The calculated risk scores resulting from the methodology, have been validated by means of the execution of a program of chemical analyses at 139 landfills, which represents a national cross section of Hungary. The measured concentration levels have been compared to background values and limit values used by the Hungarian Ministry of Environment, which resulted in following classification (see also table 5):

- I. landfills without an influenced region;
- II. landfills with an influenced region, but the B or C value for a microparameter is not exceeded;
- III. landfills with an influenced region and concentration levels of microparameters  $> B$  and  $\leq C$ .
- IV. landfills with an influenced region and concentration levels of microparameters  $> C$ .

16 of the 139 landfills (12%) are not influencing the surrounding groundwater. Some of these 16 landfills have been investigated by means of a relative small number of installed monitoring wells, which enforces the chance of missing a present mother-plume. Besides that it concerns relative young landfills, which means that emission of leachate could not yet taken place.

123 of the 139 landfills (88%) do have a zone outside the landfill, which has already been influenced by the landfill leachate. So in these zones micro-contaminants might be present. At 91 of these 123 landfills (65%) microcontaminants are present above the B trigger-value.

Comparison of the potential risk scores from the methodology and the actual measured risks based upon chemical analysis at the selected 139 landfills leads to the conclusion that they correspond very well. This means that the applied methodology can be considered as a validated and calibrated instrument.

Table 5 - Number of landfills in different categories

Categories	number of landfills	% of total number
total number of investigated landfills	139	100%
influenced region*	123	88%
not influenced region	16	12%
I no influenced region	16	12%
II concentrations $< B$	32	23%
III $B < \text{concentration} \leq C$	45	32%
IV concentrations $> C$	46	33%

\* if one or more monitoring wells outside the landfill body (A- or B-monitoring well) have been classified as influenced, the landfill is considered as a landfill with influenced outside groundwater.

## 5.2 NA-scores and NA-occurrence

The occurrence of NA is mostly dependent upon the redox-conditions of the groundwater. These redox-zones are dependent upon the age of the landfill: the older the landfill, the more redox-zones can be developed and the more the landfill itself is reduced (anaerob). The actual demonstrated redox-zones downstream the landfill differs from aerobic to iron reducing. With this information it can be predicted which microcontaminant downstream the landfill may be found or should be absent.

Comparison of the potential NA-scores from the methodology and the measured NA-potential based upon chemical analysis at the selected 139 landfills does not yet correspond very well.

The reason for this is that it concerns relatively young landfills, which are still in the initial phase of the degeneration processes. This also means that the NA-processes are still in the initial phase (aerobic circumstances), so the full-scale effect of NA (from aerobic to anaerobic) could

not yet be utilised. Besides, the majority of the investigated landfills is still operational, which means that the landfill contains a lot of recently landfilled waste. So time is too short to depend upon visible effects of the occurrence of NA at full scale.

Nevertheless it is believed that NA is a process, which actually occurs in the landfill body as well as in the surrounding groundwater influenced by the landfill, because of the following reasons:

- in a few samples the degradation range tetrachloroethene – trichloroethene – dichloroethene is found, which indicates clearly the occurrence of biodegradation of organic chlorinated compounds.
- phenols are detected in a few samples, which can indicate biodegradation of volatile organic compounds;

## 6. CATEGORISATION OF LANDFILLS AND ACTIONS TO BE TAKEN

A main distinction has been made between landfills to be closed and landfills to be used for continuing disposal of future waste. Within the last category a distinction is made between landfills to be used before and after July 2009. From this date all landfills have to meet the EU-requirements, which means upgrading of existing landfills and/or new landfills to be built. The existing landfills can be classified into 3 main categories:

1. 2551 landfills to be closed (remediation and recultivation);
2. 58 landfills to be used until July 2009 and closed (remediation and recultivation) after July 2009;
3. 58 landfills to be upgraded for permanent landfilling after July 2009;

The first and second category of landfills to be closed (2616 landfills) have been classified into risk categories, based upon the intrinsic risk score (IRS). Each risk-category has been related to types of aftercare-actions as presented in table 6. A short description of the 3 main types of action is given below:

Table 6 : Risk-categories versus type of aftercare-actions

IRS	Risk categories		Type of action		
			Groundwater-monitoring	Remediation	Recultivation
0 < IRS ≤ 2,5	A	no/less risk	X	-.-	X
2,5 < IRS ≤ 5,0	B	moderate risk	X	-.-	X
5,0 < IRS ≤ 7,5	C	high risk	(X)*	X	X
7,5 < IRS ≤ 10	D	very high risk	(X)*	X	X

\* not necessary if groundwater has been completely remediated

- **Groundwater monitoring** is consisting of:
  - Basic monitoring in order to verify in the field the absence or presence of actual risks;
  - NA-monitoring (Natural Attenuation) in order to verify the absence of future risks;
- **Remediation** is consisting of (a combination) of:
  - Excavation of waste;
  - Abstraction of contaminated groundwater;
  - Containment of an existing groundwater pollution (avoid further spread);
  - Natural Attenuation, verified by NA-groundwater monitoring (NA = aftercare measure);
- **Recultivation** is consisting of (a combination) of:

- Improvement of the surface of the landfill by a proper coverage layer;
- 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 plan of the municipality.

## 7. MAIN CONCLUSIONS AND FUTURE PERSPECTIVES

- A validated and calibrated methodology has been developed, which has been applied for the identification and categorisation of the 2667 landfill sites in Hungary and resulted in the optimisation of the actual situation of landfills and future landfill capacity;
- It concerns a **new methodology**, because it has been composed and developed by taking into account all available European expertise on investigation, ranking and risk-assessment of landfills as well as the phenomenon of **Natural Attenuation**, which is **unique** in the European context;
- In spite of the fact that the specified methodology has been tuned to a countrywide Hungarian situation, it can certainly be used in other European countries and even abroad by means of slight adjustments. For that reason this new methodology can also be considered as a **European methodology**, which might be embodied in an **EU-directive** on the investigation of landfill sites;
- In Europe thousands of landfills are present in many countries, which are not yet investigated. This number will only increase if eligible countries will join the European Community in 2004. So it can be stated that the need of a uniform, simple and cost-effective methodology, embodied in an EU-directive, is a realistic one.

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