EXAMINATION ON LANDFILLS

NEW STRATEGY AND METHODOLOGY FOR GROUNDWATERMONITORING BASED ON NATURAL ATTENUATION

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SUMMARY*: Based upon a rough estimation Europe counts more than 150.000 landfills. It 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). And at the old and abandoned landfills aftercare measures must be taken to protect the groundwater and soil from contamination, due to the lack of any environmental protection measures at these landfills. In compliance with the requirements of the EU-directive and other relevant environmental legislation, groundwatermonitoring systems should be installed, the so-called “traditional monitoring”. This “traditional monitoring” takes not into account the advancing technology with respect to “Natural Attenuation (NA)”. In collaboration with Dutch waste management companies as well as the Dutch provinces and M, inistry of Environment, Royal Haskoning has developed a new strategy and methodology for NA-groundwatermonitoring, which can be applied in the operational phase as well as in the after care phase of a landfill. This new strategy has already been applied at more than 300 landfills in The Netherlands and abroad (Hungary and Lithuania). It can be concluded that NA-groundwatermonitoring results into a more sustainable and more cost-effective strategy of groundwatermonitoring of landfills in comparison to the classic “basic monitoring” systems. The next step is to convince the Dutch and EC-authorities of the added value of NA-groundwatermonitoring in order to be able to implement NA-groundwatermonitoring at all landfills in the Netherlands and other European countries.*

1. INTRODUCTION

The exploitation and aftercare of operational and recently closed landfills are regulated by the European Union in the Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

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SUFALNET Sustainable Use of Former and Abandoned Landfills

The overall objective of the EU-directive has been formulated as follows ("quote"):

> Overall objective EU-directive
> *The aim is to provide for measures, procedures and guidance to prevent or reduce as far as possible negative effects on the environment in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from landfilling of waste, during the whole life-cycle of the landfill.*

In practice this means the complete isolation of the landfilled waste to its environment by means of bottom and top liner systems combined with everlasting aftercare (a/o groundwatermonitoring). This is the best solution considering the actual state of art, however the waste itself remains a source of pollution and the problem is not solved related to the source.

New technological developments make it possible to consider the landfill as a biochemical reactor. Natural processes (Natural Attenuation), which occur in the landfilled waste, take care of biological degradation and chemical precipitation of polluting compounds in the waste. This means that the landfilled waste will become harmless and will not be a problem anymore to next generations. In case of emission of contamination to the groundwater downstream of the landfill, natural attenuation will also take care of reduction and even elimination of this contamination.

At all 3800 existing landfills in the Netherlands traditional groundwatermonitoring systems has been installed in compliance with prevailing legislation and directives. Referring to the new technological developments, it was decided to review the existing 'traditional' monitoring systems and to look for a new strategic approach of groundwatermonitoring.

Against this background Royal Haskoning has developed a new strategy and methodology for groundwatermonitoring at landfills, which takes into account the advantages of natural attenuation. This new NA-groundwatermonitoring methodology has been tested at the first time at the existing landfill "Armhoede" in Lochem (NL).

2. VISION AND STRATEGY

The NA-groundwatermonitoring strategy is based on the theory that natural processes are taken place in as well as outside the landfill body. NA is taking care of the reduction and/or elimination of contaminants. As a result of NA (microbiological transformation, precipitation and sorption), 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.

The advantages of the implementation of NA in the new strategy of groundwatermonitoring 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.

3. OBJECTIVES

The objectives of the application of NA-groundwatermonitoring at landfills can be formulated as follows:

* to be able to have the disposal of the right (series of) data at the right time in order to take the right strategic decisions with respect to the ending aftercare of a landfill site;
* to increases the quality and reliability of decision making for both owner of the landfill site and competent authorities;
* to improve the understanding and the explanation of the absence and/or presence of certain pollutants in a certain time period;
* to improve the communication between landfill owner and competent authorities.

4. THE NEW METHODOLOGY

The main starting point of the NA-groundwatermonitoring methodology is that the chemical macro-parameters in the leachate are relatively homogeneous divided in the landfill body. The organic and inorganic micro-contaminants are more or less heterogeneous divided in the landfill body and besides they are more retarded than the chemical macro-parameters in the leachate. This means in case of leakage that first macro-parameters are emitting the landfill and will cause a “macro-plume” downstream the landfill site. If no macro-plume is detected, than also a micro-plume (micro-contaminants) can not be present (Figure 1).

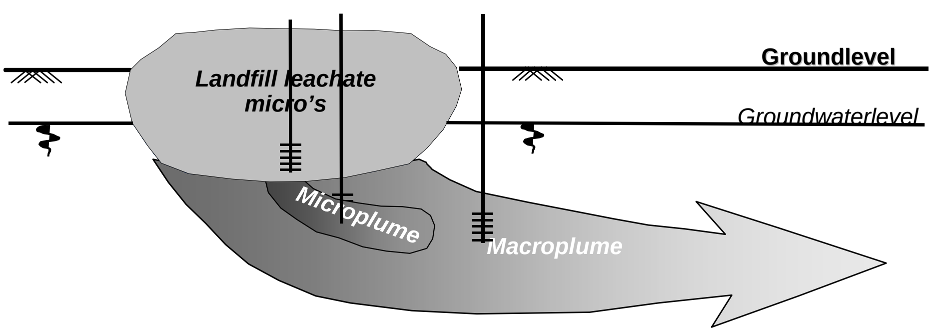

Figure 1. Emission from landfill: macro- and microplume

The first step in the methodology is to detect the absence/presence of a downstream macro-plume, which is easier, quicker and last but not least more cost-effective than detecting the absence/presence of a microplume. The macro-chemical parameters are used to define *watertypes* by means of a K-means cluster analysis. These watertypes can be defined as groundwater that has a specific (macro)chemical composition that allows identification of the level of landfill leachate influence. The purpose is twofold: finding a relation between watertype and the presence/absence of NA as well as the validation of the intended localisation of the monitoring wells. Besides the determination of the watertypes, redoxconditions are determined following the flowchart in Figure 2.

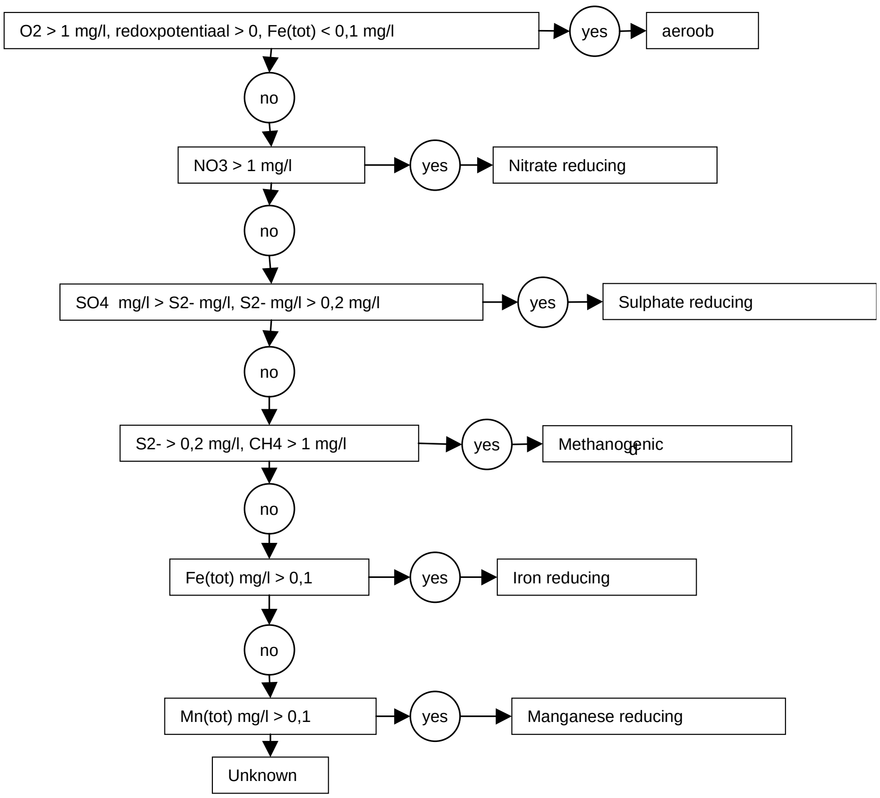

Figure 2. Flowchart determination redox-conditions

The new methodology is characterised by the following characteristic features:

- distinction between basic groundwatermonitoring (in compliance with EU-directive) and the NA-groundwatermonitoring;
- relation between results of monitoring (measurements) and measures to be taken with respect to monitoring and aftercare.
- distinction between macro-parameters and micro-parameters to be analysed.
- distinction between measurements in the landfill body (leachate) and measurements in the groundwater upstream and downstream the landfill site.

The NA-groundwatermonitoring methodology consists of a practical stepwise approach (12 steps) and is suitable for application at every landfill in the Netherlands and abroad. These 12 steps are visualised in the flowchart of the NA-groundwatermonitoring strategy of landfills (Figure 3). Application of the methodology is flexible and dynamic, because:

- there is a choice between a reactive or proactive NA-strategy;

- next measurements will always be adjusted to actual NA-situation in and outside the landfill body.

The **reactive** NA-strategy means that only “action” takes place after determination of a downstream macro-plume. So the first step is measuring the macro-parameters downstream the landfill site.
The **proactive** NA-strategy means that NA-conditions will be measured in advance, i.e. determination of the actual NA-situation in and/or outside the landfill body (watertypes, redox-conditions). Knowledge of the actual NA-situation enables:

- to get insight in unstable or already stable landfill body, which allows to predict which contaminants in the present situation can leave the landfill body and which contaminants can not leave the landfill body as a result of NA (biological degradation, chemical precipitation). This knowledge is the basis to determine the so-called **“emission risk model”** (Table 1).
- to support the decision whether NA-conditions in the landfill body might be steered and conditioned (aeration, circulation of leachate, etc) in order to optimise the NA-conditions and to reach by acceleration the favourable stable phase (final storage quality FSQ).

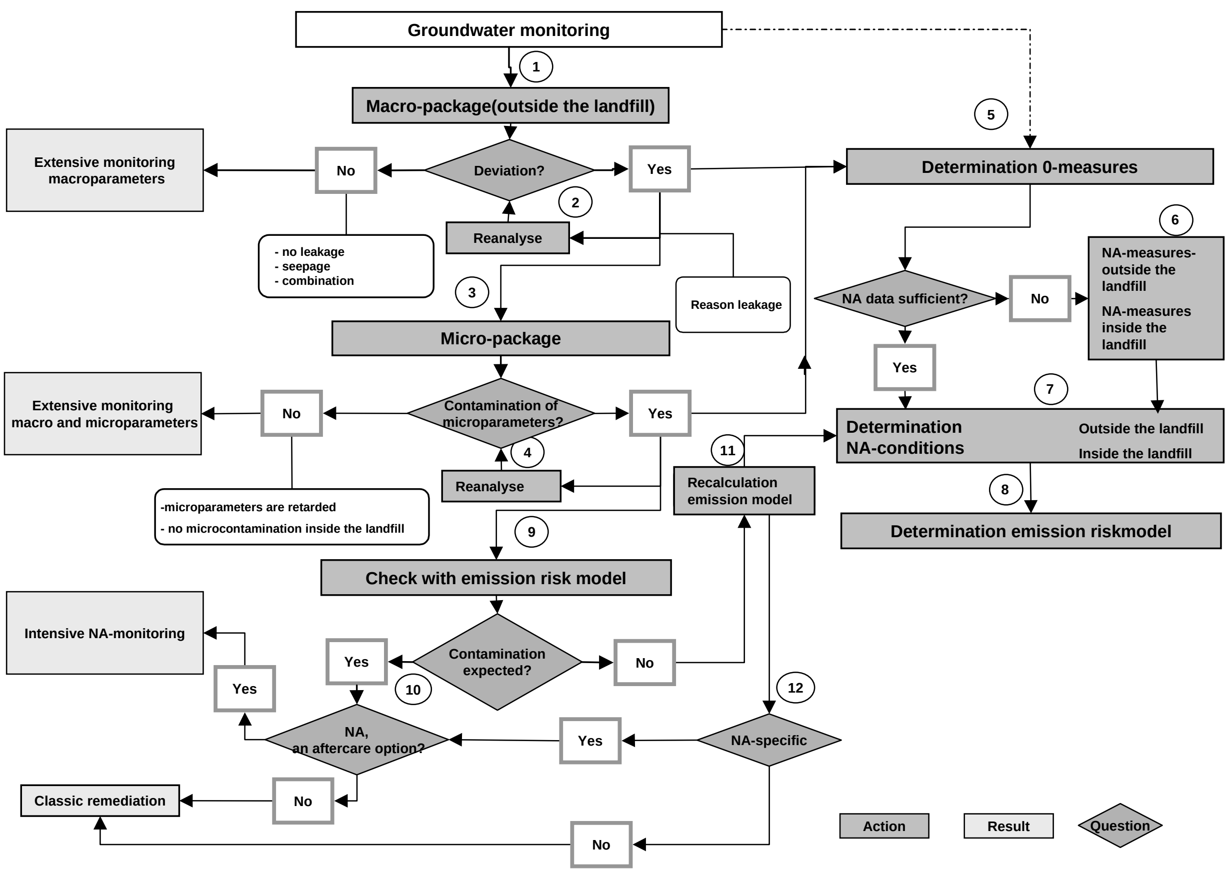

Figure 3: Flowchart NA-groundwatermonitoring of landfills

Table 1: General emission risk model

Redoxconditions	Methanogenic	Iron-reducing	Nitrate-reducing
Heavy metals	+	-	-
PAH	-	+/-	+/-
Benzene	-	+/-	+/-
Toluene	+/-	+/-	+
Ethylbenzene	+/-	+/-	+
Xylene	+/-	+/-	+
Naftalene	-	+/-	+/-
Per/Tri	+	+	+
CIS	+	-	-
VC	+	-	+
Mineral oil <C20	+/-	+/-	+/-
Mineral oil >C20	-	-	-

\+ NA conditions favourable, +/- NA conditions less favourable, - NA conditions not favourable

5. RESULTS PILOT LANDFILL

5.1 Local situation

The landfill Armhoede is situated in the rural area of Lochem (the Netherlands) directly north of the Twente-channel (Figure 4).

The topsoil (3 meter) consists of fine to coarse sands on top of an aquifer (40 meter) which consists of sandy gravel. The groundwaterflow is in the direction of a channel and the groundwaterflow velocity is about 25 m/y, but fluctuates during the seasons.

The landfill is operating since 1974. In 1994 the old part of the landfill is remediated and upgraded in compliance to the EU-regulations. A part of the contamination however is still present underneath the bottom liner of the upgraded landfill (rest soil contamination). The influence of the old landfill (contaminated groundwaterplume) and rest soil contamination is measured in the drains and the monitoring wells. Concentrations of mineral oil, COD and chloride (downstream the landfill) are higher than the reference values.

5.2 Actual situation

During the first NA-groundwatermonitoring in 2002 groundwatersamples have been taken at a selection of monitoring wells and control drains and analysed on a set of macroparameters (redoxparamaters and transportparameters).

The NA-conditions have been determined in accordance to the flow-charts (Figure 2 and 3). The redoxconditions differ between nitrate reducing (shallow groundwater) and ironreducing (deep groundwater > 7m below groundlevel.). The results have been interpreted by means of the K-means cluster analyses. This resulted in three watertypes (Figure 5):

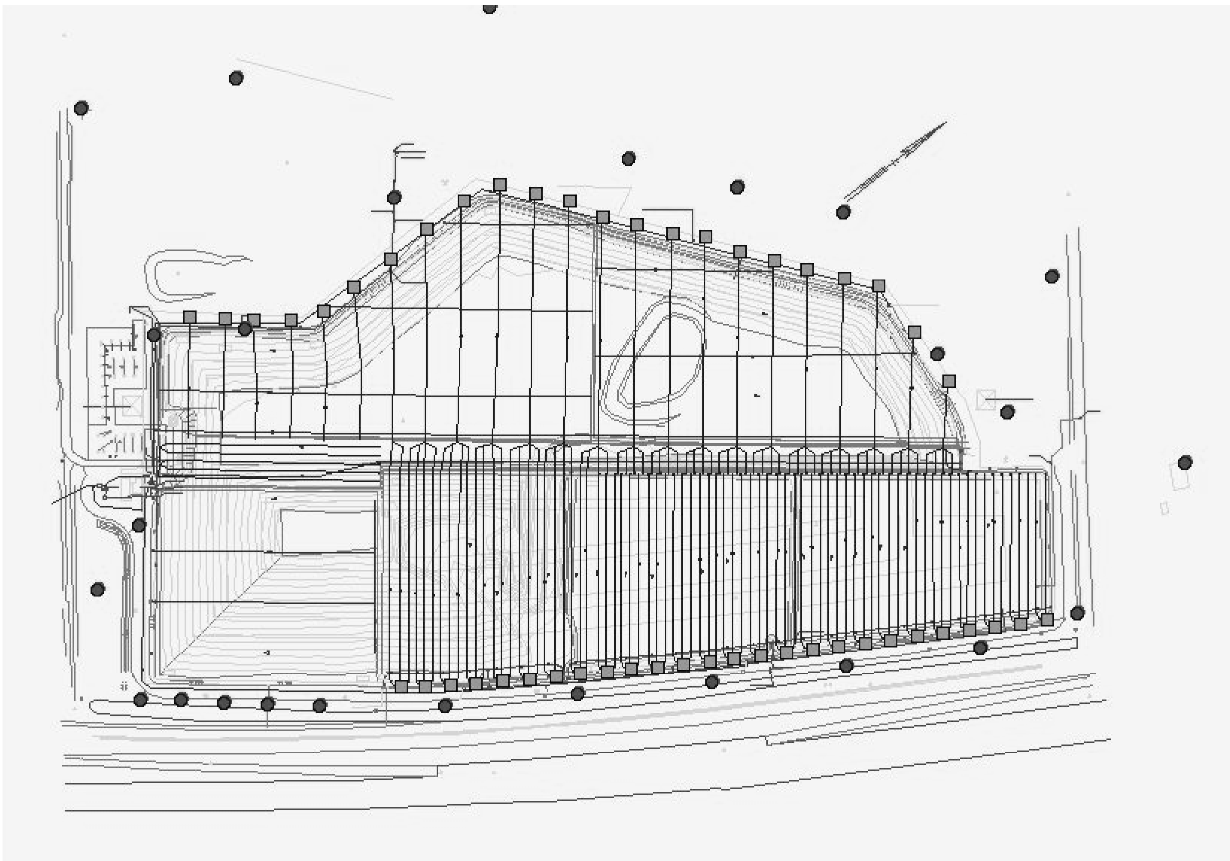

Figure 4. Landfill Armhoede (• monitoring wells)

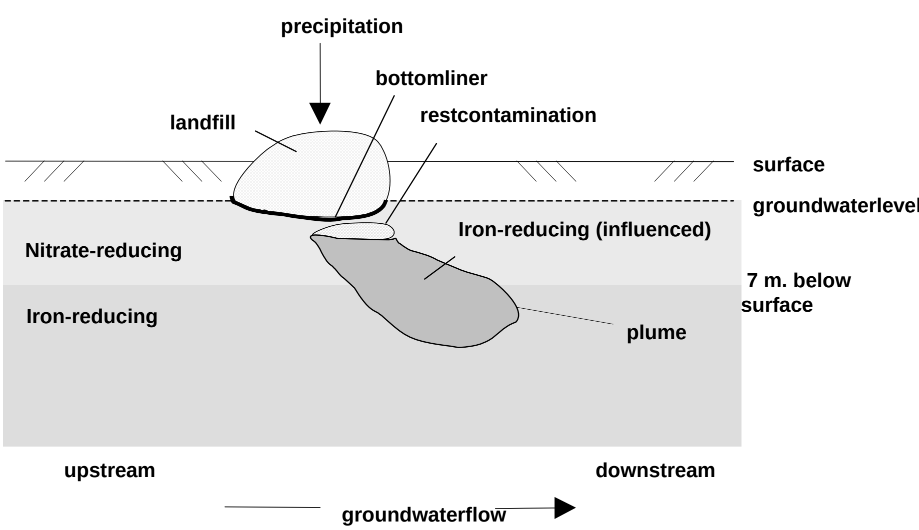

Figure 5. Presentation results interpretation macroparameters: 3 watertypes

1. nitrate reducing (no influence of the landfill/rest contamination): upstream and downstream the landfill;
2. iron-reducing (influence rest contamination): downstream the landfill;
3. iron-reducing (no influence of the landfill/restcontamination): upstream and downstream the landfill.

The three watertypes are represented by the following dominating macro-parameters, the so-called guideparameters ammonium, iron, chloride, natrium and CZV.

5.3 Comparison actual NA-situation to the emission risk model

The results of the monitoring on microparameters are compared with the emission risk model (Table 2). From Table 2 it can be concluded that the results of the monitoring on microparameters are in accordance with the emission risk model.

Table 2. Comparison results monitoring microparameters and emission risk model.

	Inside the landfill (leachate)	**Outside the landfill**	
Parameter	**Ironreducing**	**Nitratereducing**	**Ironreducing**
Heavy metals	-	-	-
PAH (heavy)	- **>I**	-	-
PAH (light)	+/- **>S**	+/-	+/-
Benzene	+/-	+	+/- **>S**
Toluene	+/-	+	+/-
Ethylbenzene	+/-	+	+/-
Xylene	+/-	+	+/-
Naftalene	+/-	+/-	+/-
Per/Tri	-	+	+
CIS	- **>S**	-	-
VC	-	+	-
Mineral Oil	- **>I**	-	-
High chloride benzene	-	-	-
Low chloride benzene	+/-	+/-	+/-

\+ NA-conditions favourable; +/- NA-conditions less favourable; - NA-conditions not favourable
>I: concentrationlevel exceeds the intervention value; >S: concentrationlevel exceeds the background concentrationlevel.)

5.4 Future monitoring

Essent proposed to continue the strategic NA-monitoring. The competent authority agreed to this proposal. The objectives are:

- monitoring the decrease of the influence of the restcontamination;

- monitoring the development of the microplume;
- proving the impermeability of the bottomliner;
- monitoring the changes of redoxconditions.

The NA-monitoring consists of the activities as presented in Table 3. In comparison to the basic-monitoring (all wells in combination with complete sets of chemical parameters and high frequency of monitoring), the NA-monitoring can be focussed upon a conscious selection of wells and drains in combination with selected chemical guideparameters and a lower frequency of sampling and analysing.

Table 3. NA-monotiring plan

Parameters	**IN LANDFILL BODY**		
		upstream	**downstream**
5 guide macro-parameters	-.-	all wells/drains every 2 years	all wells/drains every year
selected guide micro-parameters	-.-	selected wells/drains every year	selected wells/drains every year
complete set of micro-parameters*	-.-	selected wells/drains every 2 years	selected wells/drains every 2 years
5 guide macro-parameters + extra redox-parameters	every year	-.-	-.-

* selected guide microparameters are included

5.5 Cost-reduction

In comparison, a basic monitoring includes analyses on all monitoring wells and drains on a comprehensive package of microparameters. In the case of the landfill Armhoede in Lochem, the strategic NA-monitoring will decrease the costs of monitoring up to 50% in comparison to the basic groundwatermonitoring. Figure 6 shows the difference in cost up the year 2006, which results into a total cost-reduction of about € 120.000.

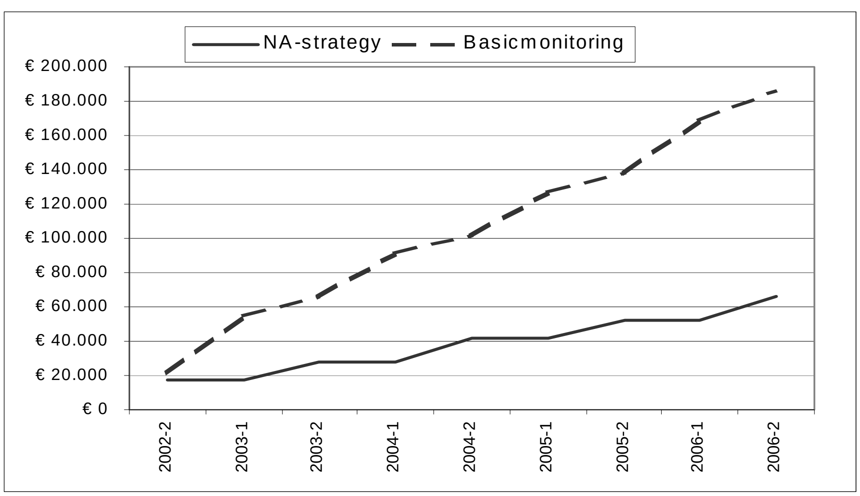

Figure 6 : Comparison costs of classic basic-monitoring and NA-monitoring

5.6 Conclusions NA-monitoring

The information generated from NA-measurements enables an expert to prove and to explain the absence and/or presence of measured contaminated compounds in and outside the landfill. This knowledge increases the quality of decision making with respect to aftercare measures for both Essent and the competent authorities. So finally it leads to an improvement of the communication between landfill owner and competent authorities.

Secondly the results of this pilot shows that NA-groundwatermonitoring decreases the costs of monitoring up to 50% in comparison to the classic basic-groundwatermonitoring. For the pilot landfill Armhoede in Lochem an average cost saving of around € 25.000 per year has been calculated. Taking into account a period of groundwatermonitoring of at least 25 years (operational phase and aftercare phase), the total cost saving of all 70 landfills in the Netherlands might amount to more than € 40 million.

6. MAIN CONCLUSIONS AND FUTURE PERSPECTIVE

It can be concluded that NA-groundwatermonitoring results into a more sustainable and more cost-effective strategy of groundwatermonitoring of landfills in comparison to the classic basic monitoring systems. Application of NA-groundwatermonitoring yields to the following profits:

- less expensive monitoring of landfills during exploitation as well as in the aftercare phase;
- ending aftercare, which leads to lower aftercare costs;
- better communication between landfill owner and competent authorities
- redevelopment of the landfill site at an earlier stage.

The next step is to convince the Dutch and EC-authorities of the added value of NA-groundwatermonitoring in order to be able to implement NA-groundwatermonitoring as daily practice at all landfills in the Netherlands and other European countries.

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