SNOWMAN NETWORK
Knowledge for sustainable soils

State of the art concerning MNA in Europe – Belgium

SNOWMAN network conference on monitored natural attenuation
November 7th 2011
Salon du Relais, Paris

Revised version

Inge Declercq

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Belgium - Flanders

1. Regulation and status

1.1. Regulatory context

The jurisdiction for soil legislation in Belgium lies with the regions. In 2008, the decree of 27 October 2006 on soil (“Bodemdecreet”) came into force in Flanders. This Soil Decree succeeds the Soil Remediation Decree (“Bodemsaneringsdecreet”) of 22 February 1995. Its focus lies on the prevention of new contamination on the one hand and on remediation of historical contamination on the other. The Vlarebo (“Vlaams reglement rond bodemsanering en bodembescherming”) regulates the practical implementation of the Soil Decree in Flanders. (OVAM, 2009)

1.1.1 Soil investigations

The Soil Decree establishes an obligation to perform soil investigations. These investigations are required when a property transfer occurs; on a periodical base or when potentially polluting installations are closed. In addition, the authorities also gather information by their soil quality investigations. In Flanders, several types of soil investigations exist. The exploratory (or preliminary) investigations include a (limited) study of the history of the soil and restricted sampling operations. When there is an indication that a contamination might be present the need for further soil investigations is determined, depending on a comparison between contaminant concentrations and soil remediation values. Descriptive soil investigations include a detailed characterisation of the contamination. Also, the risks for humans and ecosystems are determined in this type of soil investigation. A description of the contaminant quantities, concentrations and origins is given; as well as a description of the possibility that these spread further into the environment and the risks or the danger that humans, plants, animals, surface and groundwater are exposed to these contaminants.

1.1.2 Remediation

Depending on the origin of the soil contamination, a distinction for remediation is made in policy. The so-called “historical” contamination includes those contaminations that originated before the first decree of 1995 came into force; thus all contamination originating before October 29th 1995. “New” soil contaminations refer to the contamination that originate from after that date. Concerning new pollutions, the decree requires remediation as soon as soil remediation values are exceeded. In contrast, this is not the same for historical contamination: here, the decision to remediate will depend on the existing dangers to humans and to the environment. Hence, a risk assessment approach is followed during descriptive soil investigations.

In general, the remediation actions for a contaminated piece of land are fixed in soil remediation projects. OVAM, the Public Waste Agency in Flanders (“Openbare Vlaamse Afvalstoffen Maatschappij”) is in charge of supervision of the remediation.

1.1.3 Remediation obligation and liability

The Soil Decree in Flanders also includes an obligation for remediation, which lies with the operator or land owner where a soil contamination has originated. This obligation exists automatically for new contaminations; for historical contaminations, the government has to order the remediation.

The Flemish Soil Decree also introduces a liability provision: for new contaminations, this non-retroactive rule links the liability to the person(s) that caused the contamination. However, it is still possible to include other parties in the liability as well. For historical contaminations, the liability is determined by the rules that were in effect before the decree came into force.

When a land owner or operator can prove that he himself did not cause the contamination, he is not obligated to carry out the remediation operations. This is also the case when he can prove that he wasn’t and shouldn’t have been aware of the contamination when he acquired the property. In addition, in the case of historical contaminations, the operator or land owner is not obligated to perform remediation when he can prove that (a) the contaminated land was acquired before 1993 and (b) the property has been used exclusively for a non-professional use since then.

1.1.4 Concerning natural attenuation

Within the regulating framework in Flanders, natural attenuation (NA) is considered a BAT (best available technique)[1]. (Goovaerts, Lookman, Vanbroekhoven, Gemoets & Vrancken, 2007)

1.2. Status

1.2.1. Contaminated sites in Flanders

In Flanders, the Public Waste Agency (OVAM) keeps an inventory about all parcels for which information is available. This Land Information Register ("Grondeninformatieregister" or GIR) is completed through collected information when performing soil investigations. It contains separate files for each piece of land, including information on the identities of the land owner and user; cadastral data and a summary describing the soil contamination and risk activities. Optional items include reports of the performed exploratory and descriptive soil investigations; the soil remediation project; the content of the conformance certificate[2]; the statement concerning performance which is delivered when following the soil remediation procedure.

According to the OVAM activity report from 2010, the GIR contained 45.478 parcels at the beginning of January 2011. (Verheyen, 2010) However, it doesn't only include contaminated sites; clean grounds are also covered by this register! Information concerning soil contamination in Flanders is thus available in the OVAM-managed GIR.

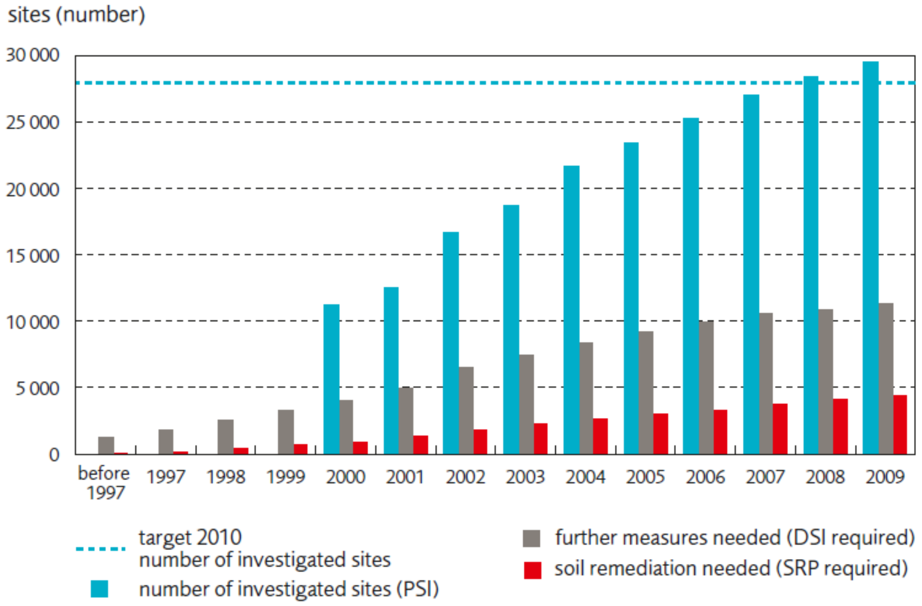

Figure 1. Investigated soils at risk in Flanders – status at the end of 2009. (Van Steertegem, 2010, p.111)

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[1] The evaluation of impacts and the cost-effectiveness of NA as a remediation technique, which are the considered criteria for evaluation of "best available techniques", are shown in Table 1 paragraph 4.

[2] Soil remediation projects in Flanders are drafted by soil experts and submitted to the OVAM. The submitted report is an description of the procedures that will be used for remediation and aftercare of the site and it includes a comparison between different remediation techniques. Evaluated aspects are e.g. efficiency, applicability, costs, timing, expected results and so on. Once submitted, the report is evaluated as to whether or not it is in conformity with relevant regulations and whether or not OVAM agrees with the proposed remediation technique. If the soil remediation project is declared conform, the OVAM decides the time frame within which the remediation has to begin. (OVAM Website)

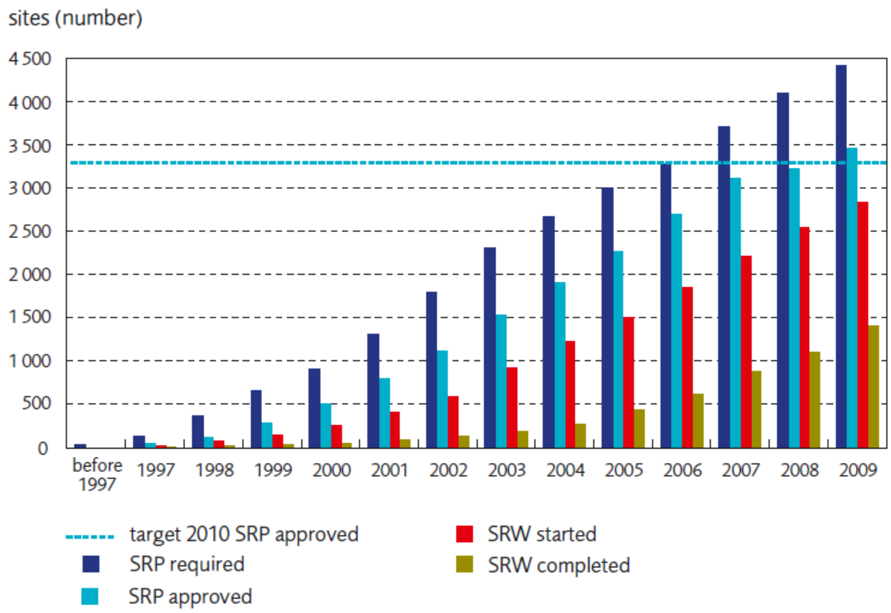

Figure 2. Contaminated sites in Flanders and the phase of remediation. (Van Steertegem, 2010, p.112)

In Flanders, it is estimated that about 85.000 soils are at risk. (Van Steertegem, 2010) Figure 1 shows how many of those sites have undergone preliminary (PSI) soil investigations. It also shows where descriptive soil investigations (DSI) or soil remediation projects (SRP) are needed. As the figure shows, at the end of 2009, OVAM had performed preliminary soil investigations at about 35% of the soils at risk. Remediation is needed for approximately 15% of the investigated sites.

Figure 2 shows the status of performed soil remediation projects and soil remediation works (SRW) in Flanders at the end of 2009. About 12.000 sites require remediation; about 3.000 of these (or 24%) have started remediation operations (SRW). For approximately 1.500 sites (12%), the remediation works have finished.

1.2.2. <u>Actual use of NA as a remediation method</u>

1.2.2.1. The use of natural attenuation

Now that we have a clear view of the situation of contaminated sites in Flanders and how many of those have undergone remediation, the question arises as to how many times natural attenuation has been used for remediation of those sites. The answer can be found in the MIRA-T report of 2010: this states that natural attenuation was applied at 435 sites in Flanders. (MIRA, 2010) From the VITO[3] publication concerning best available techniques for soil remediation, it can be deduced that this number has increased spectacularly over the last few years: only 82 NA-based remediation projects were performed for the period 1997 – June 2003. (Goovaerts, Lookman, Vanbroekhoven, Gemoets & Vrancken, 2007) However, these statistics don't differentiate between enhanced natural attenuation (ENA) and monitored natural attenuation (MNA).

1.2.2.2. The use of monitored natural attenuation

From data on approved soil remediation projects for June 2011 (indicative information collected by OVAM), it shows that enhanced natural attenuation was used 140 times, natural attenuation (the used term for MNA) was used approximately 340 times. This information, however, was derived from files filled out on an indicative basis by project managers their selves and thus it cannot be ruled out that the indication "NA" doesn't include some ENA techniques as well. (S. Van den Bulck, policy coordinator at OVAM, personal communication, 2 September 2011) Other indicative information concerning the use of NA in Flanders shows that approximately 300 conform soil remediation projects include the use of NA-techniques in combination with at least one other, non-NA-technique. The

[3] VITO is the Flemish institute for technological research.

techniques most often used in combination with NA are drainage and off-site remediation techniques. Until now, approximately 150 remediation projects which include the use of NA are finished in Flanders. (S. Van den Bulck, personal communication, 19 September 2011)

In order to obtain a better view of the use of MNA in Flanders, conversations were held with several project managers from OVAM. The MNA-related topics presented below were discussed with P. Ceulemans, head of a soil investigation and remediation unit at the OVAM (28^{th} October 2011). Other discussions included two example cases where ENA is being applied (paragraph 1.2.2.3).

Is MNA being applied for both new and historical contaminations?

Yes, MNA is possible for both. In the past (before the adjustment of the Soil Decree in 2008), discussions concerning MNA were orientated towards the fact that MNA was rather unsuited for remediation, seeing that the background values had to be obtained whenever remediation of contaminated soils was performed. These values were very strict and would require a very long monitoring time. However, the Soil Decree that came into force in 2008 allows less strict remediation goals for historical contaminations ('no more risk') meaning that currently, the required time frames for monitoring of NA doesn't pose such a big obstacle any more.

Is MNA being applied as a stand-alone technique?

MNA as a stand-alone technique, without further enhancement of the NA-processes is not widely used in Flanders. This has a few possible reasons, one due to the fact that the remediation goals in Flanders are rather strict for new contaminations, meaning that it is not possible to reach them in a reasonable time frame if one has to depend on MNA. Consequently, MNA is almost always applied in combination with active measures such as excavations and venting techniques.

Is there a difference as to how different contaminant groups are treated with MNA?

Yes, e.g. mineral oil or BTEX contaminations often require a source treatment such as excavation. MNA can then be applied as an additional measure. In these situations, there is hardly ever the need to stimulate the NA-processes. In contrast, for contaminations with chlorinated ethenes there is almost always an enhancement required as well as the monitoring of ENA. Intuitively, Mr. Ceulemans feels that there are probably some more cases of mineral oil than those of chlorinated ethenes being treated with MNA although this is a difficult estimation to make.

What is the required monitoring time for MNA cases?

This too is difficult to say, the monitoring period depends on both the kind of contaminant(s) and the extent of the contamination (concentrations)! The monitoring period is thus specific for each case.

Have there been cases where MNA was not immediately approved by OVAM for the remediation of contaminated sites?

Yes, mostly in the beginning years when MNA first gathered attention for the remediation of contaminated sites (end 1990's, early 2000's). During that time there were several consultants that put MNA forward as a very cheap and easy solution. However, there were not enough investigations of the NA-processes being performed and thus there was insufficient evidence that MNA was a feasible remediation option. On this basis, OVAM had to refuse several soil remediation projects. This 'problem' however was solved when the Code of good practice was published: this required remediation specialists to respect the guidelines and provide the required evidence of NA.

Another important aspect here is that it is often forgotten that MNA is not such a cheap alternative! The costs for monitoring are dependent on several aspects, such as the size of the contaminated area, the number of monitoring wells that is required, the parameters that have to be checked and the number of years during which monitoring is needed. However, a factor that is consequently underestimated is the costs related to reporting (i.e. wages of soil remediation specialists). A yearly cost for MNA projects of €2.000 or €3.000[4] is not impossible.

Are there MNA cases where there has been reaction against the use of MNA by residents close to the contaminated area?

This concerns very few cases, seeing that one of the criteria to allow monitoring is that the number of parties that is involved is limited.

Modelling is mentioned in the Code of good practice concerning NA; is it actually being applied in practice as well?

The use of modelling tools in practice is probably very limited. Sometimes models are used to check the degradation mechanisms of volatile organic chlorinated compounds. However, modelling requires that degradation rates are well known and this is difficult to determine. The choice is often made to monitor this in the field instead.

Are there MNA cases where it was decided to go back to active remediation measures because monitoring turned out to be insufficient?

There have been probably been some cases for volatile organic chlorinated compounds. However, when it is decided to go back to active measures, it is mostly not because of miscalculations or wrong estimations about the feasibility of MNA. The cases where it is decided to stop monitoring after active remediation and apply other additional measures instead, are those where part of the source is still present and it is unknown how this will affect the NA-processes. It is then decided to monitor for a few years in order to determine if MNA would be a reasonable option.

There are over 300 MNA cases in Flanders, yet it seems that there hasn't been an analysis of this information, i.e. in general there is very little return on experience concerning MNA, yet OVAM has access to data from over 300 projects. Why hasn't there been a report that presents the obtained results in Flanders so far?

Yes, there is a lot of information available in the files from the OVAM database, however, there hasn't been time to invest in the analysis of this data.

1.2.2.3. Examples from practice

Example cases of MNA

On the website of OVAM, there is information available on some of the remediation projects in their care[5]. This overview includes the example of a project where NA-processes are applied for remediation. The project covers a location in the harbour of Gent (Pantserschipstraat 181) where the site is contaminated by heavy metals, mineral oil and different aromatics. Part of the location was excavated and in-situ remediation (drains) was used. The monitoring of the natural attenuation of benzene was started in 2010 and is foreseen for the following five years. If the results are insufficient, active remediation of the groundwater contamination will be considered. (OVAM Website)

Another example of where MNA is applied for remediation in Flanders is a site where a factory is present which produces barrels (since 1926) and plastic containers (since 1996). In the past, also the production of gas cylinders took place (1949-1994). The site is contaminated by VOC, mainly trichloroethene. The contamination has migrated towards a residential area and is now also located underneath this area. The source zones have been treated by a dual phase approach. A hydraulic barrier is foreseen on site through pump and treat and a forest has been planted as an additional hydraulic barrier. For remediation of the plume, MNA is being applied and a reactive barrier is

[4] Intuitive estimation!

[5] The execution of soil remediation projects normally falls within the responsibility of the site owners (who are guided by an acknowledged expert). If the site owner, however, doesn't initiate the remediation himself, OVAM can do this in his/her place. In this case, OVAM claims back the costs. Another possibility in which case OVAM performs the soil remediation project is when the person whose duty it is to initiate the remediation is declared 'an innocent owner'. The remediation and its costs then fall under the responsibility of OVAM. (OVAM Website)

foreseen at the level of a large stream in order to protect this receptor. Monitoring of the plume has been applied since 2003, but the official monitoring through “MNA” has started in 2011. A detailed monitoring plan has been drawn up (e.g. number of boreholes, parameters, details for several periods: 0-3 months, 3 months -1 year, 1-10 years, …). It is planned to monitor the plume for 10 years. Measurements in the past have demonstrated that the plume is not spreading any more. There have been several investigations at the site in order to decide on a possible ENA approach (which was not maintained); as well as the drafting of a groundwater flow model and the investigations for MNA. MNA was chosen only for the remediation of the plume. MNA was not sufficient to deal with the contamination of the source and the surface water receptor (stream), hence the choice of source treatment in combination with both protection of the receptor and a plume remediation approach through MNA. Key elements to a successful MNA approach here are sufficient investigations of MNA and potential enhancement of the NA-processes; clear and timely communication with the local residents and the combination of MNA with active source-border treatment! The communication with local residents dealt with the content of the remediation project and explaining the MNA concept. The people involved also had the opportunity to react to the public investigation. Some economic aspects of this remediation are: total costs of remediation €2.000.000 (including taxes); MNA costs (without placement of monitoring wells since they are already present, this cost is not known): €25.000 for 10 years of monitoring. (M. Achten, personal communication, 31st October 2011)

Example cases of ENA

A first example of ENA concerns a historical contamination of chrome VI, volatile organic compounds (VOC) and mineral oil due to the production of car parts. The production facility was started in 1964 and is still present at the site. The origin of the contamination is probably due to the lack of environmental awareness in the past. A pilot phase for ENA was performed at four locations on the site in 2002. After this, an off-site full scale project by injections was set up (2004) and an on-site hydraulic barrier was installed. Other past remedial actions include e.g. excavations of the source zone (2010 + planned in the future), pump & treat and VOC extraction in the source zone. In 2009, the off-site injections were interrupted in order to evaluate whether or not the NA-processes still require further stimulation. So far, the results of this interruption (and simultaneous monitoring) haven’t shown clearly whether or not the decrease in contaminant concentrations is due to the injections. The enhancement of NA is monitored at least once a year and is foreseen to last until 2020. Results so far have demonstrated that the manual injection appears more difficult than was anticipated after the pilot test. The reason is not entirely clear, although it is suspected that the presence of sandstones is causing difficulties. Another problem that occurred during this project is the formation of mould in the injection pipes. Regular cleaning could help prevent this. At this point, it is expected that the remediation goals for chrome VI and VOC’s will not be obtained. Assessment of the situation is still ongoing (e.g. through measurements of indoor air). Overall, it can be said that adequate investigations beforehand, knowledge sharing and sufficient monitoring are key elements to successful ((M)NA) projects. (L. Crauwels, personal communication, 27th October 2011)

The second example concerns a contamination by VOC (with residual concentrations of BTEX and mineral oil which don’t require remediation measures). The site was used in the past for the assemblage of telecom equipment (until 2009). The origins of the VOC contamination are situated at a former collecting basin and storage area of solvents. Remedial actions include the excavation of one source zone (unsaturated zone), a pilot test for the stimulation of micro-organisms (started in 2009 and still ongoing) and groundwater removal which is still ongoing. The results of the pilot test so far show a slow start of the biological degradation, probably due to the high speed of the groundwater flow (20-40m/year) and the low pH-values that came to be in the injection area (limited buffering capacity of the soil). Also it appears that there might be incomplete degradation. Currently, it is foreseen to repeat the pilot test in the source zone that has been excavated. The first source zone will be monitored and the density of the filtration network will be increased. In June 2011 laboratory tests for anaerobic degradation were started on soil and groundwater samples. Initially, it was foreseen to reach the remediation goal within a period of nine years. The problems during this project (e.g. incomplete degradation) and the results so far indicate that this project will probably last longer than was first anticipated. So far, the overall costs for the remediation project are about €180.000. (R. Van Teghem, personal communication, 17th October 2011)

1.2.3. NA in research: locations in Flanders

Natural attenuation has been and is being studied at several research sites in Flanders. For example, two locations (in Mechelen and in Mortsel) were studied within the framework of the sustainability of NA. Another example includes the Zenne river. Furthermore, the international ENACT project included a site in Antwerp. Projects will be discussed in paragraph 2.2.2. Furthermore, the Code of good practices mentions that the developed guidelines are being applied at two locations and that reports about these cases will become available at a later time[6].

[6] These reports are not yet publicly available, but it is foreseen that the results will be included in the revision of the Code of good practice concerning NA. (N.Bruneel, personal communication, 27 October 2011)

2. Documents and projects

2.1. Existing documents

These documents only include existing documents concerning MNA in Flanders.

2.1.1 OVAM: Code of good practices for NA (2003)

This publication from 2003 includes literature overviews concerning NA of petroleum hydrocarbons, chlorinated hydrocarbons, inorganic compounds and existing guidelines; OVAM guidelines for the evaluation of the applicability of NA; recommendations for monitoring programs and a discussion of sampling methods. The code of good practices will be discussed in paragraph 3.1.

OVAM. (2003). *Code van goede praktijk – Natuurlijke attenuatie*. Mechelen: OVAM.

2.1.2 Sustainability of NA (2010)

In 2010, OVAM published a project report to evaluate the sustainability of NA of benzene, toluene, ethylbenzene and xylene (BTEX). In this study, the bioavailability of iron(III) is evaluated through three different methods. The project will be discussed in paragraph 2.2.2.

OVAM. (2010). *Duurzaamheid van anaerobe natuurlijke attenuatie op sjtes verontreinigd met BTEX*. Mechelen: OVAM.

2.2. Research projects

2.2.1 SEDBARCAH: biodegradation in river beds

Biodegradation of groundwater contaminants which are transfered to the river and the impact of the presence of microbial communities in sediments on this biodegradation process were studied in the SEDBARCAH project (2005-2007; SEDiment bioBARriers for Chlorinated Aliphatic Hydrocarbons in groundwater reaching surface water). This project is coordinated by VITO and includes partners from the Netherlands, Germany and the Czech Republic. The project focuses on chlorinated aliphatic hydrocarbons (CAH) and includes two river beds: the Zenne in Belgium and Bělá in the Czech Republic. The project aims are among others to monitor the role of sediments on biodegradation (during eighteen months); to develop guidelines on how to measure, describe and stimulate degradation of groundwater contaminants infiltrating the sediment zone and to examine the implementation of the stimulated biobarrier technology as a remediation technology.

Results were among others that biodegradation by reductive dechlorination is the main process of CAH elimination at the Zenne site; the sediment which includes a CAH-degrading microbial community is a natural biobarrier against the release of CAH into the surface water and stimulation of the CAH degradation will be necessary in the aquifer upstream of the Zenne river. For the Bělá river too, sediments can act as a natural biobarrier for CAH present in groundwater. (Project website; Website NARCIS)

2.2.2 Sustainability of the NA of BTEX

A study was performed in Flanders concerning the sustainability of NA of BTEX. After all, when the presence of NA has been demonstrated at a site, it doesn't necessarily mean that this NA potential is enough to remediate the contamination during a sufficient time period. Within the context of this study, three methods were evaluated to determine the amount of Fe(III) in soil samples[7]. Two locations were selected where the residual concentrations are eligible for NA remediation under iron-reducing conditions. For both sites, the biodegradation potential for BTEX and the decrease in available electron acceptors were evaluated.

[7] The sustainability of NA is determined by the available amount of electron acceptors. Fe(III) is considered to be the most important electron acceptor for the NA of petroleum hydrocarbons.

The first site is located in Mechelen and includes a soil and groundwater contamination with mineral oil, BTEX and MTBE (methyl tertiary butyl ether). Part of the contamination has been excavated. The soil and groundwater samples were characterised before starting microcosm degradation tests. The relation between NA of BTEX and the consumption of Fe(III) was evaluated through comparison of concentrations (at different times and at different locations). NA with Fe(III) as an electron acceptor was demonstrated for this site; but although laboratory results showed that NA is working for the groundwater contamination of BTEX, it is not working for MTBE. (M)NA was not implemented at this location; after soil sampling and field measures for this study, the site was excavated and a groundwater treatment was performed by pump&treat.

The second site is located in Mortsel. It is contaminated by mineral oil and BTEX. The site was excavated and residual concentrations are being monitored. Soil and groundwater samples were characterised and laboratory degradation tests were performed. NA was demonstrated for BTEX and the demonstrated electron acceptor was Fe(III). It was shown that Fe(III) concentrations can support the further NA of BTEX. Monitoring of the site show that the contamination plume is stable (NA of BTEX occurs) but that there is still pure product being supplied which inhibits or masks the NA in the central zone.

(OVAM, 2010)

2.2.3 SNOWMAN project ENACT

OVAM, along with the Dutch organisation SKB and the German UBA, helped finance a research project called "Extending the Monitored Natural Attenuation Toolbox for Chlorinated Solvents" (ENACT), which was funded during the first project call of SNOWMAN. This project started in 2007 and ended in 2009. The project studied the potential to use the analytical technique compound specific stable isotope analysis (CSIA) for demonstration of natural attenuation. The method was applied at three field sites (two in the Netherlands and one in Antwerp, Belgium) contaminated with chlorinated solvents. (Volkering et al., 2009)

3. Guidebooks and methodologies

3.1. OVAM Code of good practices concerning NA

The Code of good practices concerning (M)NA was published in 2003 by OVAM. The document includes an overview of physical and biological processes that are part of NA (chapters 1-6); a literature study of existing methods to assess NA-feasibility for active remediation (chapters 7-8); the Flemish guidelines to assess NA-feasibility (chapter 9) and an overview of available methods for both the detection and the monitoring of NA[8] in the field (chapters 10-11).

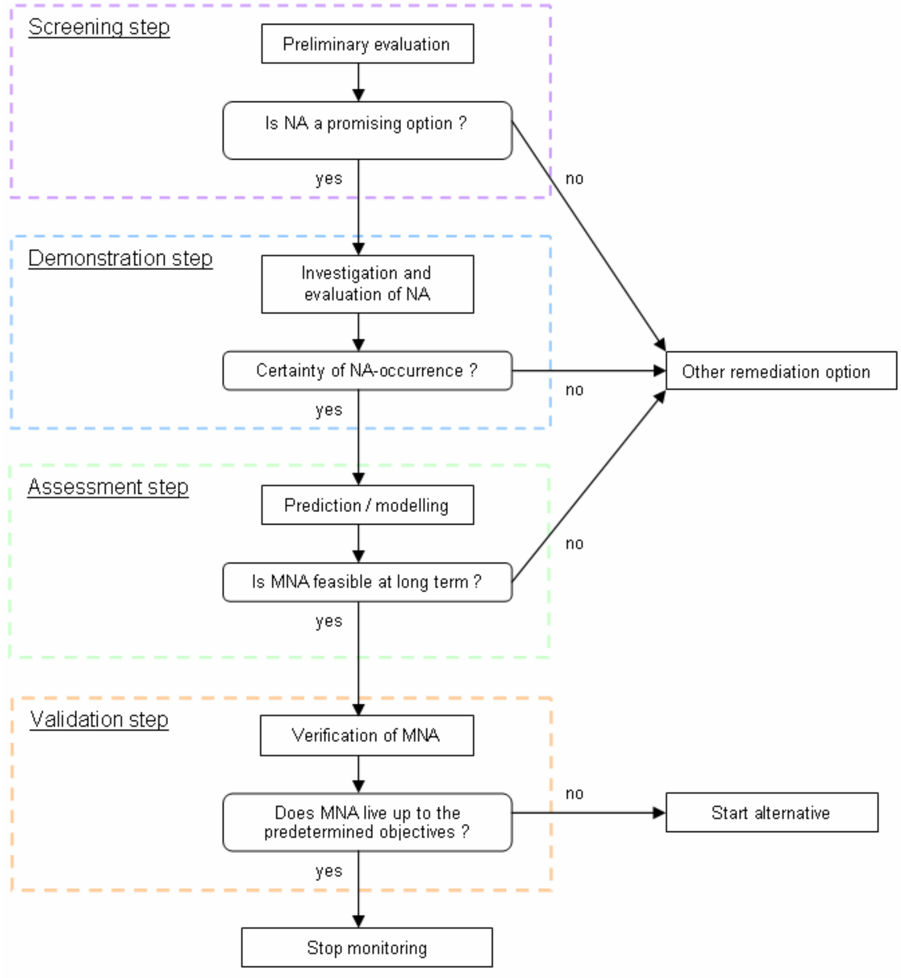

Figure 3. Evaluation of MNA as a remediation technique. (OVAM, 2003, p59)

3.1.1 <u>Evaluation of MNA as a remediation technique</u>

The Code of good practice offers guidance on the evaluation of MNA as a remediation technique. These guidelines are based on the UK Environment Agency publication of 2000 called “Guidance on the Assessment and Monitoring of Natural Attenuation (MNA) of Contaminants in Groundwater”.

The Flemish guidelines mention several criteria for the acceptance of NA as a remediation technique:

- the requirement that adequate monitoring is performed, in order to demonstrate that NA occurs and persists;
- the criteria that the remediation objectives should be achieved within an acceptable time period which doesn’t exceed 30 years;

[8] The focus in the last two chapters lies on the NA of petroleum hydrocarbons in groundwater.

- the criteria that there should be sufficient evidence provided to OVAM as to demonstrate that receptors are sufficiently protected both during and after the monitoring and that there is no significant increase in the contaminant plume;
- the criteria that, if remediation targets are not met over time an alternative active remediation method is selected and applied.

The manual presents four stages for the evidence of MNA acceptability (Figure 3).

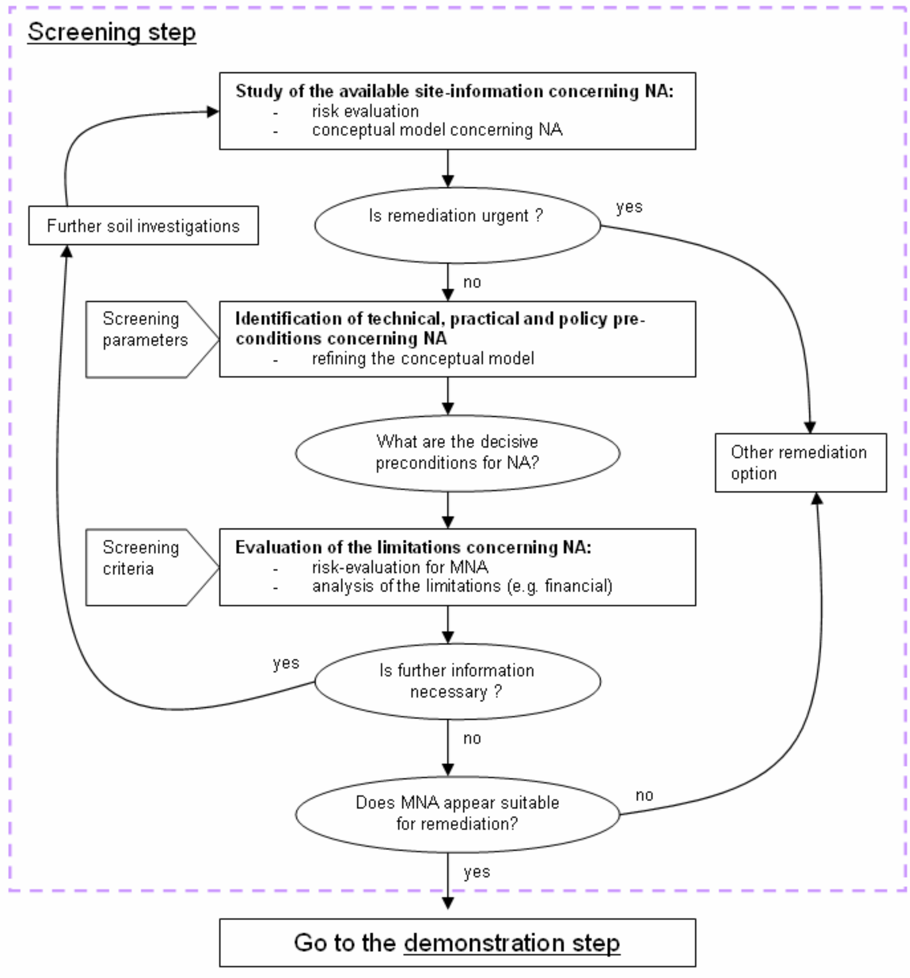

Figure 4. Flowchart: evaluation of MNA as a remediation technique – screening. (OVAM, 2003, p.61)

1. Screening stage

This stage includes technical, practical and economic feasibility as well as acceptance by regulators and the public. The flowchart of the screening stage is presented in Figure 4. The guideline mentions the minimal data that should be collected, evaluated and included in the soil remediation project as part of this screening phase. When these screening criteria are assessed as 'beneficial' or 'intermediate', the demonstration phase can begin. Furthermore there are a few of those screening criteria that are defined as 'breaking points'. When one of the 'breaking points' is selected, MNA is found to be unfeasible as a stand-alone remediation technique.

2. Demonstration stage

This stage encompasses three lines of evidence: primary evidence or trend analysis over a minimum period of three years, in order to demonstrate significant decreases in contaminant concentrations. The secondary evidence aims to show that e.g. daughter products or metabolites are generated, electron donors/acceptors are present as well as to demonstrate that the contaminant plume is stable or shrinking. The tertiary evidence includes the demonstration of complete degradation through e.g.

laboratory tests[9]. This last line of evidence is not mandatory if NA was demonstrated in the first and second line of evidence.

The OVAM publication also mentions the use of mathematical models to determine the evolution of the concentrations and the speed of NA.

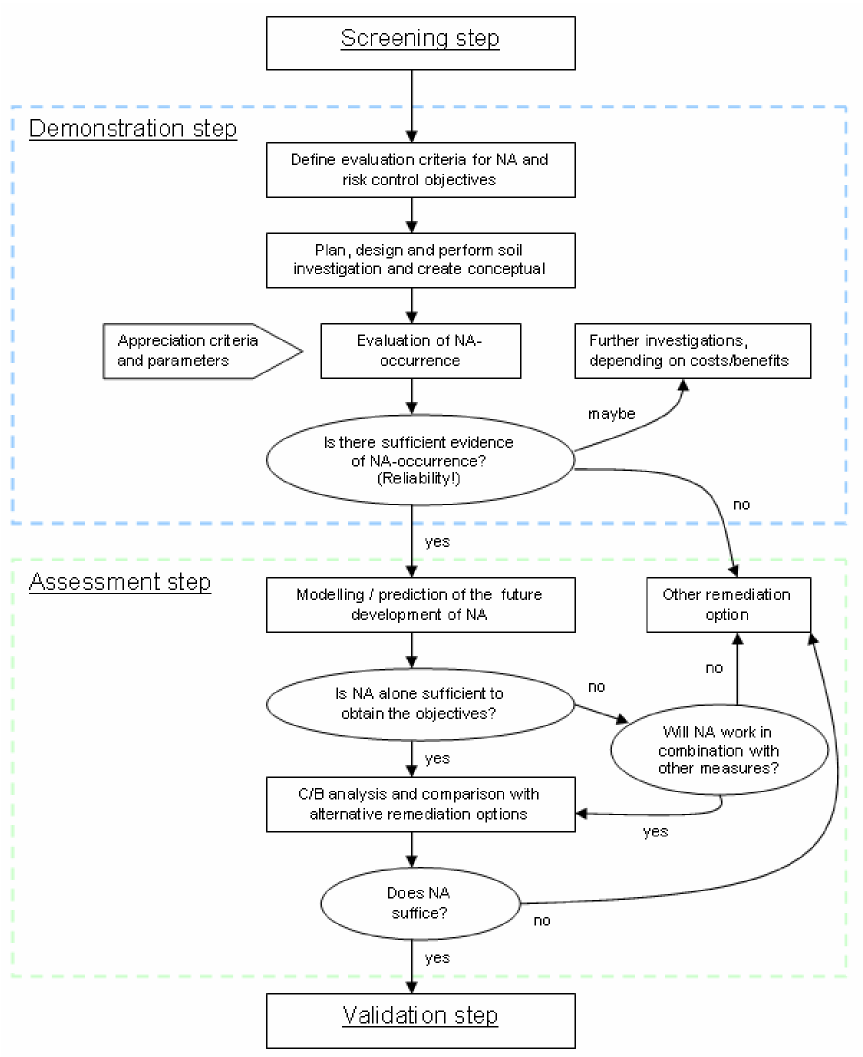

Figure 5. Flowchart: evaluation of MNA as a remediation technique – demonstration and assessment. (OVAM, 2003, p.65)

3. Assessment stage

During this phase, the future development of the NA processes is evaluated. Questions have to be asked about the acceptable time frame within which the goals have to be reached, about the limitations to NA (shall NA continue to occur or are there limiting factors such as nutrient shortage?), and so on.

The future distribution rate should be assessed while at the same time taking into account the attenuation that has been determined so far (e.g. through groundwater flow models which incorporate transport modules). Also: the evaluation of the plume development should include effects of e.g. source removal and previously performed remediation measures.

[9] These laboratory tests also contribute to the examination of possible NA stimulation (e.g. adding nutrients or electron donors), which can be developed as (a part of) the alternative remediation method should MNA be unfeasible.

This stage also includes the development of a monitoring program. The demonstration and assessment stages are presented in Figure 5.

When OVAM approves the soil remediation project which describes the screening, demonstration and assessment stage for NA, the validation stage can begin.

4. Validation stage

This stage includes the implementation of the NA monitoring, comparison with established remediation goals, etc.

3.1.2 Monitoring

When it is decided to implement MNA, it is important to monitor the contamination itself, together with geochemical and hydrogeological parameters. In other words: the implementation of MNA requires verification that the contamination plume is shrinking or stable. The OVAM publication concerning good practices lists the minimum requirements for the monitoring program:

- demonstrate that MNA occurs as has been predicted;
- identify any toxic by-products;
- check whether the contaminant plume grows;
- ensure that no sensitive recipients are threatened;
- take into account the possibility that new releases or changes in the environment might influence the MNA effectiveness;
- verify that the remediation objectives are obtained.

A monitoring plan must be set up that fixes at least the following aspects of MNA: the monitoring period (how long?), the sampling frequency (when?), the location of the sampling points (where?) and the parameters and sampling methods (what?).

- Where? At least at: the source; downstream of the source (in the non-contaminated area); downstream of the contamination; downstream where there's no contamination but where concentrations of electron acceptors are lower compared to unaffected groundwater; alarm/trigger points downstream of the contamination plume (at the parcel boundaries) and lateral (and sometimes within) the contamination plume.
- What? Contamination concentrations; metabolites and side products; geochemical indicators (dissolved oxygen; nitrate; sulphate; dissolved inorganic carbon[10]; conductivity; …), temperature, pH, oxidation-reduction parameters, groundwater levels, and so on.
- When? The frequency to sample and measure should allow the detection of the migration of the contamination plume, while taking into account seasonal changes in hydrology. The intervals cannot exceed the time that is needed for the contamination plume to reach an uncontaminated monitoring well.
- How long? At least until the contamination has reached the defined target values, increased by a few years to confirm these values.

Furthermore, the code emphasises that this is an iterative process! The continuous evaluation and adjustment of the monitoring program is a crucial aspect to the MNA concept. This also means that the intensity of the monitoring program can be adjusted at any time. Furthermore, an essential element of the monitoring program is an action plan that determines what has to happen when NA proves not as successful as had been estimated.

(OVAM, 2003)

[10] DIC is the sum of dissolved CO_2, bicarbonate and carbonate.

3.2. Techniques

3.2.1 Methods to determine NA-parameters

The OVAM publication mentions several existing methods to determine significant parameters relating to NA of petroleum hydrocarbons (listed below). The Code of good practices refers to the VITO website for information on sampling, analysing methods and sample conservation.

(1) Oxygen

- Chemical: Winkler titration method (in the lab);
- Electrochemical: electrodes in the field.

(2) Nitrate and nitrite

- Ion chromatography;
- Colorimetric determination;
- Use of a specific electrode.

(3) Fe^{2+} and manganese

- Spectrophotometry;
- Immediate field filtration;
- Measurement through colorimetric field methods.

(4) Sulphate

- Ion chromatography;
- Liquid chromatography;
- Precipitation methods.

(5) Sulphite: colorimetric method

(6) CO_2

- In the laboratory: DIC determination or gas chromatography (GC) in combination with TCD-detector;
- Alkalinity analysis through titration and from this a determination of dissolved CO_2;
- In the field: portable GC in combination with FID (flame ionization detector);
- Analysis in soil air or headspace (e.g. Landfill Analyser).

(7) Methane: GC in combination with FID or TCD (thermal conductivity detector)

(8) Hydrogen

- GC;
- Specific detection method for concentrations in the groundwater lower than 5ppb: RGD (reduction gas detector).

(9) Stabile isotopes

- Carbon isotopes:
    - o Mass spectrometer for isotopes;
    - o Determination of the isotope ratio.
- Isotopes of hydrogen, sulphate and chlorine: determination of shifts in stable isotope ratios

(10) Alkalinity and conductivity: titration

(11) Oxidation-reduction potential: combination electrode (galvanic cell)

(12) Intermediary products of biodegradation

- Phenols: by using the phenol index or by GC/MS;
- Carbon acids: GC/FID.

3.2.2 The evaluation of Fe(III) bioavailability

The OVAM publication concerning sustainability of NA of BTEX (2010) mentions several methods to evaluate the Fe(III) bioavailability:

(1) HCl-extraction (0.5M with ferrozine determination);

(2) Extraction with ammonium oxalate at pH3;

(3) Sequential extraction with dithionite, citrate and bicarbonate;

(4) Ti(III)-EDTA titration;

(5) *Shewanella*-microcosm tests;

(6) Anthraquinone-2,6-disulfonate (AQDS) – oxidation.

4. Lessons from the application of (M)NA

The VITO publication from 2007 concerning best available techniques for soil remediation also discusses the use of NA. It mentions e.g. the costs, impacts on the environment related to the application and the obstacle for implementation in Flanders. (Goovaerts, Lookman, Vanbroekhoven, Gemoets & Vrancken, 2007)

- *Obstacle for the application in Flanders*

The publication mentions that NA as an alternative for active measures will most likely only be applied at larger surfaces. This counteracts the application of NA in Flanders, which is densely populated, resulting in parcels with smaller surface areas than e.g. in the USA.

- *Costs*

The authors state that the costs related to the preliminary investigation to determine the feasibility of NA can be significant. The financial risk of applying NA is thus of consideration.

- *Environmental pressures and impacts*

Concerning the impact of the application of NA on the environment, the VITO publication mentions the low energy costs related to this technique. The publication sums up the effects of NA as a remediation technique, they are shown in Table 1. The indexes '+'; '0'; '-' and '+/-' respectively stand for: causing a positive effect; no impact; a negative effect and sometimes positive, sometimes negative effects.

Table 1. Assessment of NA as a remediation technique: impacts. (Goovaerts, Lookman, Vanbroekhoven, Gemoets & Vrancken, 2007, p.199)

Technical impacts	Useful in practice: proven?	+
	Safety	0
	Quality	0
	Global	+
Environmental impacts	Water	+
	Raw materials	0
	Air	0
	Soil	+
	Waste	0
	Energy	0
	Noise	0
	Global	+
Cost-effectiveness		-

5. Return on experience

The “return on experience” refers to the results from MNA for the remediation of contaminated soils in practice (thus not in research programs). This includes information on e.g. possible obstacles during implementation, reasons for success or failure of the applied MNA program, information on actual costs and duration of the remediation and, most importantly, the achieved results of remediation of contaminated sites.

We can say for certain that in January 2010, natural attenuation was applied at 435 sites in Flanders. (MIRA, 2010) Secondly: approximately 340 projects included MNA according to information collected in June 2011 by OVAM. (S. Van den Bulck, personal communication, 2 September 2011) Furthermore, approximately 150 remediation projects which include the use of NA were finished until September 2011. (S. Van den Bulck, personal communication, 19 September 2011) We also know for a fact that the first formally accepted soil remediation project in Flanders which included MNA started in 1998. (S. Van den Bulck, personal communication, 14 October 2011)

In general, the use of MNA in Flanders leads to the following conclusions:

- MNA can be applied for both historical and new contaminations;
- MNA as a stand-alone technique is not widely used in Flanders due to the combination of strict remediation goals and the need for reasonable timeframes within the MNA concept;
- Consequently, MNA is almost always applied in combination with active measures;
- The tendency of consultants to put forward MNA as a cheap and easy solution without actual proof of NA-occurrence (in the early 2000’s) changed due to the publishing of the protocol for NA;
- Costs are often underestimated, especially with regard to costs for hiring soil remediation experts;
- Although it is mentioned in the guidelines, the practical application of modelling seems limited;

From the example cases in paragraph 1.2.2.3 we can learn that it is imperative that adequate investigations of the NA-processes are performed beforehand! Other key elements to successful (M)NA projects include clear and timely communication, knowledge sharing, problem anticipation & reaction and sufficient monitoring.

Finally, although there is a lot of information available for each of the approximately 340 MNA projects in Flanders, until now, there has been no investigation or analysis of this information. This database offers a great potential for return on experience of MNA!

6. Timeline

Figure 6 represents the timeline for Flanders. There are a few research projects concerning NA, originating from OVAM in Flanders, which took place during the period 2004-2010 approximately. Information on other research projects is not included in this overview. Concerning NA, there is one general methodology in Flanders, which is still the relevant protocol today. The first soil remediation project which included MNA and which was formally accepted by OVAM, dates from 1998. Natural attenuation is still being implemented today.

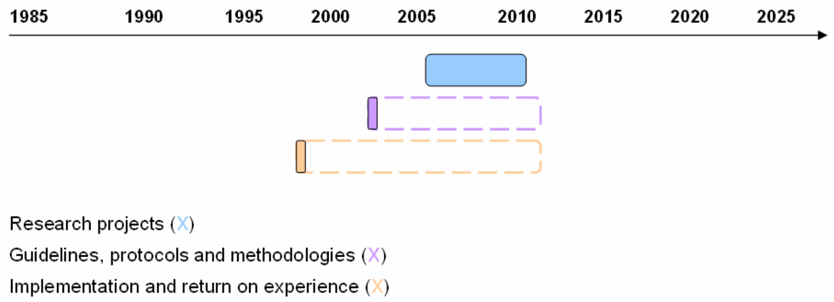

Figure 6. Timeline for Flanders.

Belgium – Walloon Region

1. Regulation and status

1.1. Regulatory context

Specific legislation in the Walloon Region concerning soil remediation dates from April 2004. The Walloon Decree from 5 December 2008 covers the management of soils; this set in movement the formation of an inventory of (possible) contaminated soils in the Walloon Region. (DGARNE, 2010)

As explained in the SPAQUE ("Société Publique d'Aide à la Qualité de l'Environnement"; or the public corporation for support on the environmental quality) publication of 2010 (Cahier de bonnes pratiques n°9), the use of MNA (monitored natural attenuation) is accepted as a remediation technique within the framework of the decree from 2008. (Halen et al., 2010) The code of good practices concerning soil remediation in the Walloon Region is foreseen for the end of 2011 (CWBP – Code Wallon de Bons Pratiques). This document will be based on the good practices from the corporation SPAQUE. (Website Environnement Wallonie)

1.2. Status

1.2.1. Contaminated sites in the Walloon Region

According to information in the publication from DGARNE (Direction générale opérationnelle de l'Agriculture, des Ressources naturelles et de l'Environnement, 2010), so far the inventory of possible contaminated sites as covered by the decree from 2008, holds information on 1302 dump sites (of which 1/3rd has undergone remediation); 2338 gas stations (half of which don't pose any more threat of soil contamination)[11] and 7577 former industries[12]. The publication from 2010 also mentions that this inventory isn't complete yet. The information for the database was provided by DGARNE, DGATLPE and the corporation SPAQUE.

An inventory on contaminated sites for the Walloon Region called "Walsols" (from the corporation SPAQUE) can be consulted online. It does however, not allow to filter on applied remediation techniques.

No statistics were found on the use of MNA in the Walloon Region.

1.2.2. Application of NA in the Walloon Region

The annual report from corporation SPAQUE for the year 2009 mentions that the existence of NA-processes is unsatisfactory as a single remediation method. So instead, they apply "surveillance environnementale" after remediation of contaminated sites.

The SPAQUE report mentions numbers for the use of "surveillance environnementale" at sites from the Walsols database for the last five years. Information on financial means is included (Table 2). Also included in the annual report from SPAQUE is a list of the 43 sites in their portfolio (for 2009) where "surveillance environnementale" is applied (Figure 7). Figure 8 represents the financial resources needed for the monitoring of those sites. In both figures, the objective of the company is presented in pink, the actual obtained number of sites and money spent (in 2009) in presented in green.

Although the report lists the 43 sites by name; no further information is presented on e.g. the monitoring duration, obtained results, obstacles, etc.

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[11] This information was collected up to December 2009.

[12] Information from DGATLPE (3921 sites of which 1481 no longer in use) and SPAQUE (3656 sites, 1304 of which are at high risk of contamination); data collected until September 2009 and January 2010 respectively.

SPAQUE refers to “surveillance environnementale” as the adjusted follow-up and monitoring of contaminant concentrations during multiple years. ‘Surveillance environnementale’ is performed by the corporation for contaminated soils, industrialised sites and discharges from dump sites. It is not explicitly mentioned in the consulted publications what this environmental surveillance entails. Hence we cannot be entirely sure that this is the full equivalent of MNA, e.g. has there really been an NA-investigations phase where the presence of NA-mechanisms has been determined?

Table 2. Application of NA after remediation – information from SPAQUE and the Walsols database. (SPAQUE, 2009, p.81)

Year	***“Surveillance environnementale”: # of sites***	***Financial amount (€)***
2005	47,3	244.659
2006	30,9	226.583
2007	33,6	62.166
2008	41,5	236.330
2009	43	130.731

Figure 7. SPAQUE: number of sites under “surveillance environnementale”. (SPAQUE, 2009, p.84)

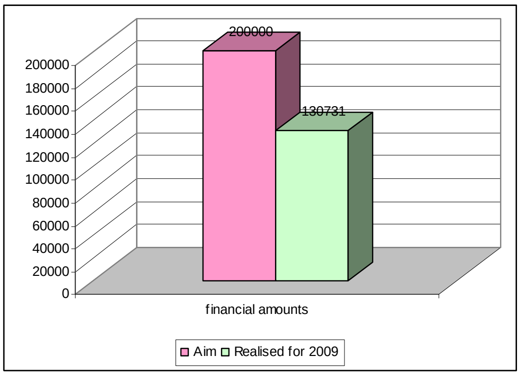

Figure 8. SPAQUE: financial amounts for “surveillance environnementale”. (SPAQUE, 2009, p.84)

2. Documents and projects

2.1. Existing documents

2.1.1. Cahiers de bons pratiques – SPAQUE

The corporation SPAQUE has published several methodologies concerning soil remediation. These will serve as the basis for the Walloon Code of Good Practices for soil remediation which will be published in the end of 2011. The "Cahiers" from SPAQUE discuss elements associated with the use of natural attenuation as a remediation technique (most importantly Cahier n°8, which will be discussed in paragraph 3.1).

Vandenheede, V., Dengis, P. & Scauflaire, P. (2010). *Guide pour l'étude d'orientation – Cahier des bonnes pratiques n°2 (CBP-2-1.1-1001)* . Liège : SPAQUE.

Beuthe, B., Jailler, M., Le Bel, M., Leclercq, J., Dengis, P., Lox, A. & Vandenheede, V. (2010). *Guide pour l'évaluation des risques : santé humaine, eaux souterraines, écosystèmes – Cahier des bonnes pratiques n°5 (CBP-5-1.1-1001)* . Liège : SPAQUE.

Lansival, V., Halen, H., Namèche, T., Vounaki, O., de Viron, O. & Nuyens, D. (2010). *Lignes directrices pour le contrôle et le suivi des travaux de réhabilitation – Cahier des bonnes pratiques n°8 (CBP-8-1.1-1006)* . Liège : SPAQUE.

Halen, H., Moutier, M., Beuthe, B. Namèche, T. , Vounaki, O. & Nuyens, D. (2010). *Rapport de l'évaluation finale – Cahier des bonnes pratiques n°9 (CPB-9-1.1-1006)* . Liège : SPAQUE.

2.2. Research projects

No information was found online about research projects concerning natural attenuation in the Walloon Region.

3. Guidebooks and methodologies

3.1. Good practices for the control and follow-up of remediation projects

This guidebook (#8) was published by the company SPAQUE in 2010 and will form the basis for a Walloon code of good practices. (Website Environnement Wallonie) The introduction of the guidebook explains that the publication includes methodologies for performance measurement of remediation projects; for post-operational controls and for control of the NA remediation procedure. It also mentions that this protocol is primarily based on several publications from OVAM, such as the Code of good practices concerning NA.

3.1.1. Collection of information

The guidebook mentions that certain information is required before the start of a remediation project that relies on NA-processes:

- the initial concentrations of contaminants and the location of the contamination plume;
- an estimation of the future development of concentrations, the amount of contaminants that will be removed and residual concentrations.

3.1.2. Sampling

Before the monitoring can begin, a plan has to made which includes rules for sampling and measurements. This plan should include:

- the sampling period;
- the sampling frequency;
- the locations of where the samples have to be taken;
- the definition of parameters.

A list of possible parameters is also included in the guidebook.

3.1.3. Objectives of the monitoring program

When NA is chosen as a remediation concept, the contamination as well as geochemical and hydrogeological parameters should be monitored. This monitoring program should (at least) include the following objectives:

- demonstrate that the NA occurs as foreseen;
- identify the degradation products (toxic?) and verify if biodegradation will be complete;
- make sure the contamination plume doesn’t become any larger;
- make sure that sensitive receptors aren’t threatened;
- evaluate the changes in the environment that could affect the NA-processes;
- verify that the remediation objectives are fulfilled.

(Lansival et al., 2010)

4. Return on experience

Although the company SPAQUE published both a list of the 43 remediation projects in their care that include “surveillance environnementale” (in 2009) and the financial costs related to this monitoring; there is no further information about these projects available online. We cannot be completely sure that this concept is equal to the MNA approach for remediation of contaminated sites. There were no examples of remediation projects found online that use MNA as part of the remediation strategy.

Additional references

DGARNE. (2010). *Rapport sur l'état de l'environnement Wallon – Tableau de bord de l'environnement Wallon 2010*. Jambes : DRAGNE.

Goovaerts, L., Lookman, R., Vanbroekhoven, K., Gemoets, J. & Vrancken, K. (2007). *Best Beschikbare Technieken (BBT) bij het uitvoeren van bodemsaneringsprojecten en bij grondreinigingscentra*. Mol: VITO.

MIRA. (2011). *Achtergronddocument 2010 - Thema Bodem*. Aalst: VMM.

OVAM. (2009). *Vlaams reglement rond bodemsanering en bodembescherming*. Mechelen: OVAM.

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SPAQUE (2009). *Rapport annuel 2009*. Liège: SPAQUE.

Van Steertegem, M. (2010).*MIRA Flanders Environment Report – Indicator Report 2010*. Aalst: VMM.

Verheyen, J. (2010). *OVAM activiteitenoverzicht 2010*. Mechelen; OVAM.

Volkering, F., van Breukelen, B., Elsner, M., Gemoets, J., De Ceuster, T., Sakaguchi-Söder, K. & Veld, H. (2009). *Project No. SN-01/24 ENACT: Extending the Monitored Natural Attenuation Toolbox for Chlorinated Solvents – Final research report*. Netherlands: Tauw.

Regulatory context:

Vlaamse Gemeenschap. (2006). *Decreet betreffende de bodemsanering en de bodembescherming - 27 oktober 2006*.

Vlaamse Overheid. (2007). *Besluit van de Vlaamse Regering houdende vaststelling van het Vlaams reglement betreffende de bodemsanering en de bodembescherming – 14 december 2007*.

Waalse Gewest. (2004). *Decreet tot sanering van verontreinigde bodems – 1 april 2004*.

Waalse Overheid. (2008). *Decreet betreffende het bodembeheer – 5 december 2008*.

Websites:

Environnement Wallonie : code de bons pratiques http://dps.environnement.wallonie.be/GestAction.

MIRA http://www.milieurapport.be.

NARCIS: SEDBARCAH http://www.narcis.nl/research/RecordID/OND1309765.

OVAM http://www.ovam.be/jahia/Jahia/pid/5.

OVAM, project Gent harbour http://www.ovam.be/jahia/Jahia/pid/2388.

SEDBARCAH project http://wwwa.vito.be/sedbarcah/.

VITO http://www.vito.be/VITO/NL/HomepageAdmin/Home/home/.

Walsols http://www.walsols.be/.

List of abbreviations

BAT	best available technique
BTEX	benzene, toluene, ethylbenzene and xylene (volatile organic compounds)
CAH	chlorinated aliphatic hydrocarbons
CSIA	compound specific stable isotope analysis
CWBP	Code Wallon de Bons Pratiques
DGATLPE	Direction Générale Opérationnelle de l'Aménagement du Territoire, du Logement, du Patrimoine et de l'Energie
DGARNE	Direction générale opérationnelle de l'Agriculture, des Ressources naturelles et de l'Environnement
DSI	descriptive soil investigation
ENACT	Extending the Monitored Natural Attenuation Toolbox for Chlorinated Solvents
FID	flame ionization detector
GC	gas chromatography
GIR	grondeninformatieregister
MIRA	milieurapport Vlaanderen
(M)NA	(monitored) natural attenuation
MTBE	methyl tertiary butyl ether
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij
ppb	parts per billion
PSI	preliminary soil investigation
RGD	reduction gas detector
SEDBARCAH	SEDiment bioBARriers for Chlorinated Aliphatic Hydrocarbons in groundwater reaching surface water
SKB	Stichting Kennisontwikkeling en Kennisoverdracht Bodem
SPAQUE	Société Publique d'Aide à la Qualité de l'Environnement
SRP	soil remediation project
SRW	soil remediation works
TCD	thermal conductivity detector
UBA	UmweltBundesAmt
VITO	Flemish institute for technological research
Vlarebo	Vlaams reglement rond bodemsanering en bodembescherming
VMM	Vlaamse Milieu Maatschappij
VOC	volatile organic compounds