Monitored Natural Attenuation

Option for plume management

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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Summary

In some cases, under favorable conditions (mainly depending on the contaminant properties and the specific hydrogeological settings), some natural processes (i.e. that takes place without human intervention - active remediation action), may protect the environment from harmful impacts efficiently and persistently. The natural attenuation processes include a variety of processes that reduce the mass, toxicity, mobility, volume or concentration of contaminants in soil and groundwater.

Concepts have been developed to make use of monitored natural attenuation (MNA) as a management option for contaminated land and groundwater. It may being applied as a stand-alone technique, in parallel with active measures or - more frequently - as a follow-up measure to close up an active remediation.

MNA is not to be considered a walk away approach. The MNA approach typically includes several elements such as a qualitative and quantitative evaluation. This means that it must be clearly demonstrated that natural attenuation (NA) processes occur on site and objectives are determined (e.g. emphasis on environmental protection targets or for risk/hazard prevention or a combination of both). Moreover, MNA should always include two essential aspects: source control and an established surveillance plan which describes the planned long term monitoring of the site.

MNA concept has been gaining attention during the 2000 decade. In Europe, though guidelines exist in some countries, MNA was so far only applied at smaller or medium-sized contaminated sites where required data could be obtained at reasonable costs. The discussion regarding the best practice of employing MNA as a contaminated land management option, particularly at very large and complex contaminated sites (so-called megasites or urban areas), is still ongoing. Lack of return on experience may constitute a blockage point into the further acceptance of MNA.

Taking account of this situation, this report has been set up in the frame of CityChlor to stress the MNA situation in Europe (historic of MNA concept, similarities and differences between concept and application, failure and success reasons …) with a contribution to share return of experience and recommendations for the application of MNA at urban areas.

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List of abbreviations

BTEX	benzene, toluene, xylene, ethylbenzene
cDCE	Dichloroethene
CHC	chlorinated hydrocarbons
NAPL	non-aqueous phase liquid (DNAPL: dense … ; LNAPL: light …)
ENA	enhanced natural attenuation
MNA	monitored natural attenuation
NA	natural attenuation
PCE	Perchloroethylene
PAHs	polycyclic aromatic hydrocarbons
TCE	Trichloroethylene
VC	vinyl chloride
VOC	volatile organic compounds

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1 Introduction

1.1 CityChlor and the integrated approach

Space is scarce in Europe. Even in the subsurface it is getting busier. Large-scale soil and groundwater contamination with chlorinated solvents are often an obstruction for urban developments. The traditional way of dealing with polluted soil and groundwater does not work in all cases and is not economically and sustainable feasible. In urban environments multiple contaminations with chlorinated solvents are often mixed with each other and spread underneath buildings. This not only leads to technical problems for remediation, but also to liability and financial discussions and hence has an impact on society. An integrated approach and area-oriented approach is needed to tackle the problems. The CityChlor project has demonstrated that remediation and sustainable development can evolve on a parallel timescale.

An integrated approach combines all aspects that are relevant to tackle the problems that pollution with VOC in urban environment causes. Depending on area, site and context different aspects together or parallel to each other can be used. Not only technical solutions are included, but also socio-economical aspects as urban development, communication, financial and legal aspects, time, space, environment and actors (active & passive) have to be handled.

CityChlor did not remain at single case remediation, but looked at the area as a whole in a bigger context: the area-oriented approach. A technical approach that makes it possible to remediate, monitor and control multiple groundwater sources and plumes within a fixed area.

1.2 CityChlor and technical innovations

The managing of knowledge and technical innovations are one of the key to achieve a sustainable city development. A development project has to cope with loads of information coming from different disciplines in different (technical) languages and with different uncertainties. With chlorinated solvents, the knowledge about the pollution will always have a certain uncertainty that can have an impact on the course and the costs of the remediation. An efficient 'managing of knowledge' will try to decrease this degree of uncertainty.

CityChlor therefore also worked on the technical aspects of characterization and remediation. The conventional techniques that are applied for investigation and remediation have their limitations dealing with chlorinated solvents. Promising innovative techniques exist, but do not easily find their way to current application. This barrier is often caused by lack of knowledge on different levels. Experts and contractors do not always have the means to invest in experiments with new techniques, authorities are reluctant to accept techniques of which the results may be uncertain and clients aren't eager to pay for experimental techniques.

Dissemination of knowledge can break this deadlock. CityChlor therefore collected experiences from field application of innovative techniques and implemented itself a number of techniques in pilot projects. For the detailed outcomes, the reader is referred to the specific reports.

CityChlor - “new solutions for complex pollutions” **http://www.citychlor.eu/**

2 Natural attenuation concepts

2.1 Definitions

The **natural attenuation (NA) processes** include a variety of processes that reduce the mass, toxicity, mobility, volume or concentration of contaminants in soil and groundwater. Natural attenuation takes place without human intervention. The in-situ processes can refer to physical, chemical or biological processes and include biodegradation, dispersion, dilution, sorption, volatilization, radioactive decay, chemical or biological stabilization, transformation and destruction of contaminants.

Monitored Natural Attenuation (MNA) refers to the use of NA as a remedy or management option that is based on the reliance that NA processes are able to achieve site specific remediation or management objectives. Monitored natural attenuation should always include two essential aspects: source control and long-term performance monitoring.

MNA is not to be considered a walk away approach, but rather an option for plume management or an alternative way to achieve remediation targets. It is emphasise that MNA should only be maintained as an option if and when it meets all relevant criteria and site management goals.

The term "**enhanced natural attenuation" (ENA)** refers to the supporting, the stimulation or the enhancement of the biological activity of the natural attenuation processes (bioaugmentation, biostimulation). After primary / actives methods (removal or destruction of source, plume treatment as pump and treat (P&T), …), ENA technique is often applied in order to ensure faster, easier and better remediation results as to assure the plume will stabilize and shrink.

2.2 Mechanisms of natural attenuation

NA processes may be classified as either non-destructive processes, which do not destroy the contaminant but transfer it to another compartment or attenuate its concentration within a compartment, or destructive processes, which destroy contaminants via chemical or biological processes. These processes can be divided into four categories:

- non-destructive processes that do not modify the mass of contaminants within a compartment (e.g., groundwater or the gaseous phase): advection, dispersion, and molecular diffusion. Advection, the "transport engine" of compounds in groundwater, does not reduce concentration levels on its own;
- non-destructive processes that modify the mass of contaminants within a compartment, which includes all phase transfer processes: dissolution, volatilization (NAPL/gas and water/gas transfers), and sorption;
- destructive processes: mainly biodegradation and, to a much lesser extent, chemical degradation (in particular for 1,1,1-TCA);
- non-destructive phenomena grouped under the word "dilution," which does not refer to any physical process such as the processes described above and involves mixing of polluted and non-polluted water due to the action of various phenomena (e.g., recharge by rain or pumping in a well).A distinction can be made between

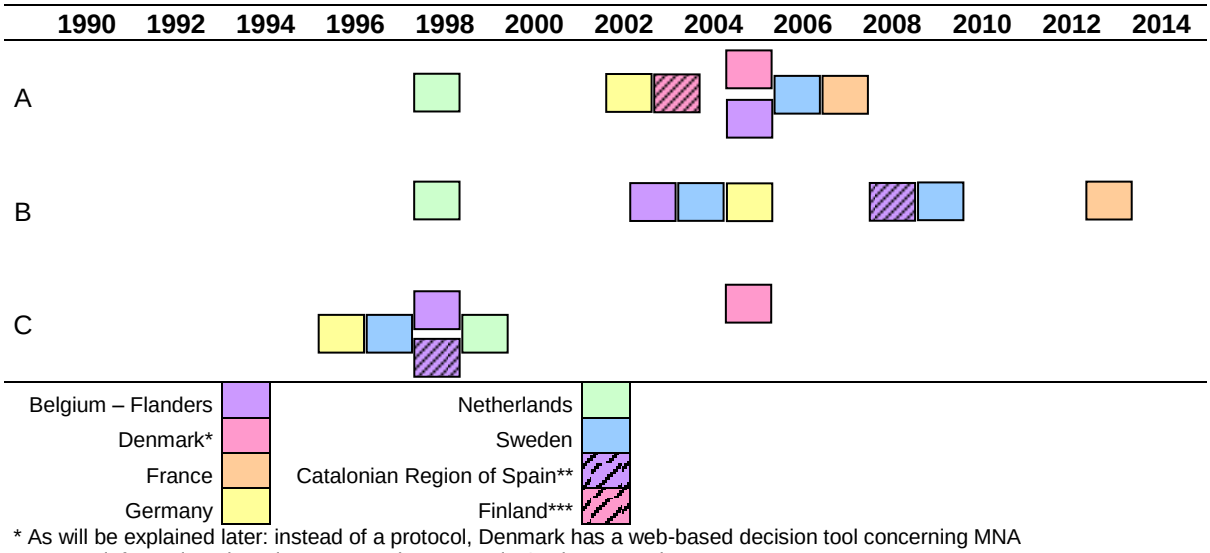
3 MNA approaches in Europe

3.1 MNA history in Europe

The most important research programs concerning NA in Europe were mainly conducted in the early 2000's. Figure shows that publication of the primary protocols were followed during the years 2000 and that these protocols followed research rather quickly.

Independent protocols for deciding whether MNA is a feasible site management option or not exist in the Netherlands (BOS-NA in 1998), Belgium (OVAM in 2003), Germany (LABO in 2005), Sweden (SGI V541-1 on petroleum hydrocarbons in 2004 and SGI V601 on chlorinated aliphatic hydrocarbons in 2009) and the Catalonian region of Spain (in 2008). The ATTENA project in France has developed such a protocol in 2013, although technical guides were published within the framework of the MACAOH R&D program in 2006. In Denmark, there exists a web-based decision tool for remediation of contaminated sites that includes MNA. There is no Finnish protocol on the evaluation of MNA as a remediation option.

For most countries, experts mention that first case of real-life MNA application took place at the end of the 1990's. A remark in order here is that, in contrast to the dates of the research programs and of the protocols, it is hard to verify whether these application dates are entirely correct. Nonetheless, this overview gives us an idea of when the MNA concept was introduced in Europe.



* As will be explained later: instead of a protocol, Denmark has a web-based decision tool concerning MNA
** To our information, there is no research program in Spain concerning NA
*** MNA is being applied in Finland but we were not able to confirm the start date of the first case

Figure 1. MNA history in Europe: start dates of the most important research programs (A); publication dates of protocols (B) and 1st case applications (C).

The NICOLE network initiative completes this picture. In 2005, a NICOLE survey described the current approach to investigate the possibility to apply MNA as a sound remedial alternative at contaminated sites. As financially the costs of full removal are not in line with the benefits and risks involved, the NICOLE demonstration project underlined that in this perspective, MNA is a cost effective option that can be used to obtain satisfactory results.

Related to the national regulatory frameworks concerning soil remediation, and even if there's no strictly delimitation, approaches for the use of MNA as a contaminated land management option may be divided into two groups:

- countries where MNA is (mainly) considered within a risk-based framework, i.e. an approach that is focused on existing risks, e.g. human health-oriented contaminated land management concepts - USA, UK, France. These concepts generally focus on existing risks and do not, in most cases, define groundwater as a principle receptor.

- countries where MNA is considered (at least partly) as a concept of soil and groundwater protection - Denmark, Germany, Belgium (Flanders) and Spain (Catalonia). These concepts are usually ''limit-based'', that is, groundwater in itself is regarded as the principal receptor and decision making is mainly controlled by fixed compliance criteria for groundwater.

In the Netherlands and in Sweden, the MNA concept is focused on the protection of soil and groundwater as well as on existing risks.

Key learning point

MNA concept has been gaining attention during the last few years. As part of a risk based site management plan or as one of the tools to manage historical soil and groundwater pollution, MNA is incorporated into the various soil and groundwater policies in European member states.

Protocols and real application are two interacting aspects. Seeing that the applications date from before the publications of the protocols, it is safe to assume that they don't follow the required steps. It could be interesting to evaluate real-life cases of MNA where the different steps of the protocol have been performed. That way we can get a true image of the dynamic between research, existing protocols and real-life application.

3.2 Differences and similarities between MNA protocols

The following part of this chapter will deal with the differences and similarities between the existing European protocols.

3.2.1 Consideration of the (non-)saturated zone

Different approaches exist within the protocols for MNA application: sometimes the protocols only consider the saturated zone, sometimes the non-saturated zone is considered as well.

MNA is considered in the saturated zone only in Spain (Catalonia) and in Germany.

The Netherlands and Denmark don't specify.

The other countries consider both the saturated and the non-saturated zone.

3.2.2 Three lines of evidence

The three lines of evidence as described by the US EPA are:

(1) Historical groundwater and/or soil data that demonstrate a decreasing contaminant mass and/or concentration.

(2) Indirect evidence of natural attenuation processes on site through hydrogeological and geochemical data.

(3) Data from field or microcosm studies which demonstrate directly the occurrence of biodegradation (or other processes).

The SGI protocols from Sweden, the Flemish Code of good practice concerning NA and the MNA guide for Catalonia all mention the three lines of evidence explicitly.

The LABO position paper (Germany) also takes into account similar evidence, although it is formulated in another way. In Germany the stationarity of the plume is an important prerequisite. The plume length has to be estimated and known. In addition, the LABO position paper also mentions the rate of the mass flow as a requirement for the evaluation of NA.

BOS-NA (Netherlands) only mentions a few elements of the three lines of evidence: the historical date considered in the first line of evidence and a possibility for additional degradation measurement (this fits into the third line of evidence).

3.2.3 Number of steps

Although the considered protocols use different descriptions and the several elements that add to the decision making process are broken down in a different way (three to five steps), they seem to be based on the same steps when considering MNA for management of contaminated sites. In general, those basic steps include the ones presented in Figure 2.

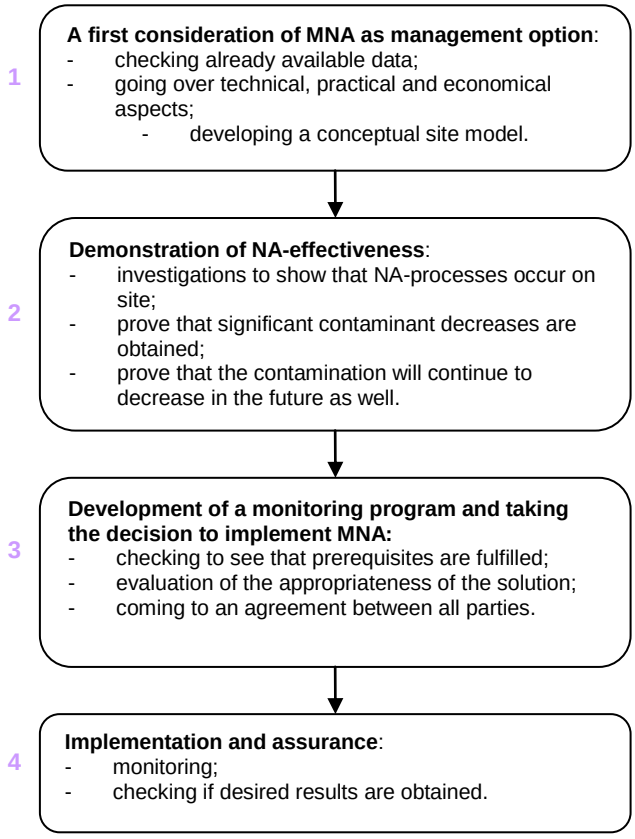


Figure 2. What basic steps can we find in the different protocols?

The first step corresponds with the checking of available data, going over technical, economical and practical aspects and the development of a conceptual site model. We can find these elements in the following (existing) steps in the different countries:

> "Screening" (Flanders) / "Checking prerequisites" (Germany) / "First traffic light" (Netherlands) / "Initial MNA assessment" (Sweden) / "Detailed MNA assessment" (Sweden) / "Characterisation of the situation" (France) / "Conceptual model and preliminary evaluation" (Spain)

The second step corresponds with performing NA-investigations, as well as proving a significant decrease and sustainability in the future. The different countries use the following steps to describe this:

> "Demonstration" (Flanders) / "Assessment" (Flanders) / "Proof of the effectiveness of NA-processes and preparation of the MNA concept" (Germany) / "First traffic light" (Netherlands) / "Second traffic light" (Netherlands) / "Detailed MNA assessment" (Sweden) / "Modelling" (Sweden) / "Feasibility study" (France) / "Lines of evidence" (Spain)

The third step includes the checking of prerequisites, evaluation of the solution and coming to an agreement between all parties. The following steps in the different countries correspond with this:

"Assessment" (Flanders) / "Administrative decision on the suitability and implementation of MNA" (Germany) / "Third traffic light" (Netherlands) / "Exposure analysis and approval" (Sweden) / "Long term monitoring" (Sweden) / "Treatability study" (France)

The fourth step includes implementing the monitoring and assurance of this monitoring. This corresponds with the following steps in the different countries:

"Validation" (Flanders) / "Carrying out MNA" (Germany) / "Fourth traffic light" (Netherlands) / "Long term monitoring" (Sweden) / "Implementation of monitoring" (Spain) / "Long term monitoring" (Spain) / "Establishment of a surveillance plan" (France)

	Belgium (Flanders)	***France***	***Germany***	***the Netherlands***	***Sweden***	***Spain (Catalonia)***
Step 1	screening	characterisation of the situation	checking prerequisites	1st traffic light	initial MNA assessment detailed MNA assessment	conceptual model and preliminary evaluation
Step 2	demonstration assessment	Feasibility study	proof of the effectiveness of NA-processes and preparation of the MNA concept	1st traffic light 2nd traffic light	detailed MNA assessment modelling	lines of evidence
Step 3	assessment	Treatability study	administrative decision on the suitability and implementation of MNA	3rd traffic light	exposure analysis and approval long term monitoring	
Step 4	validation	establishment of a surveillance plan	carrying out MNA	4th traffic light	long term monitoring	implementation of monitoring

Figure 3. Four general protocol steps: overview of the different countries.

Key learning point

The different protocols use various descriptions of the steps needed for the evaluation of MNA as a site management method, but as **Fout! Verwijzingsbron niet gevonden.** shows: there is conformity as to what these steps should include!

3.2.4 NA mechanisms eligible or not in MNA protocols

Although most countries base their definitions of (M)NA on those from the US EPA, there are several differences between the mechanisms that are accepted for MNA in Europe (destructive / non-destructive processes, dilution, volatilization, …).
Some countries include e.g. a primary NA-process: they require that a certain mechanism (biodegradation) is dominant in order to use MNA as a remediation technique. Also, sometimes certain processes are not considered within the framework of MNA (volatilisation and dissolution).

	Flanders	France	Germany	The Netherlands	Sweden	Denmark	Catalonia
Primary mechanism that should be present	biodegradation	destructive process	bio-degradation	bio-degradation	bio-degradation	biotic process	no
	abiotic degradation	isolating process	chemical transformation			dilution	
	sorption	*	sorption			volatilisation	
			**			adsorption	
Mechanisms that are not accepted for MNA	dilution	-	-	all other processes	-	-	no
	volatilisation						
	reversible sorption						
	reversible precipitation						
	***						

* at least on of the two

** should override dilution processes

*** MNA is not accepted if one of these processes is dominant

Figure 4. Primary and rejected mechanisms for MNA.

Key learning point

It is sometimes assumed that all the mechanisms that are part of the definition of natural attenuation are accepted for applying MNA in real-life management of contaminated soils. However, the protocols or guidance documents concerning (M)NA always include some further explications of the accepted mechanisms for MNA.

There are some differences between the different European countries, but at the same time there is a certain sense of coherence: almost all countries push forward the importance of biodegradation.

3.2.5 Timeframe

The Flemish guideline from 2003 explicitly mentions the criteria that the remediation objectives have to be obtained within a time period of 30 years. This is meant to give a general framework in which the remediation has to be finished; an assessment for each separate case is performed within the drafting of the soil remediation project.

BOS-NA (Netherlands) doesn't attach a fixed timeframe, but mentions it should be decided upon by reasonable judgement for each situation.

LABO from Germany, the Catalonian guide, the Swedish protocols and the French ATTENA protocols don't recommend a maximum period to reach the objectives.

Key learning point

In general the timeframe, during which the monitoring of NA should reach the management objectives, has to be decided by reasonable judgement and it should be adapted to the specific situation.

3.2.6 Modelling

In general, the place and role of modeling is to be precise as the choice of modelling (flow and transport, only flow, flow, transport and reaction…) must answer clear objectives. Although described differently, the application of modelling is the same in all these protocols: the assessment of the plume development in order to determine

(a) if site conditions are fit for the use of MNA and

(b) if the reduction of contaminants is sufficient, also in the future.

The protocols for Flanders, Germany, France and Catalonia simply mention the use of modelling

In the Dutch and Swedish protocols however, modelling is indeed a separate step and thus compulsory.

Key learning point

Modelling is a fixed element of every protocol concerning MNA, whether it is mandatory or simply recommended. However, personal contacts with people from the field indicate that this modelling is probably not always applied in practice. Indeed: complex and large cases of real-life application of MNA rely partly on this technique but in contrast, the small cases of MNA application often don't include modelling as part of the assessment for MNA-feasibility.

3.3 Germany

German position paper:

As a result of the German research-programme “Controlled natural retention and degradation of contaminants in course of the remediation of contaminated soil and groundwater” (KORA - Kontrollierter natürlicher Rückhalt und Abbau von Schadstoffen bei der Sanierung kontaminierter Grundwässer und Böden) and in order to improve the practical implementation of NA-approaches, the German Länder working group Soil (LABO - Länderarbeitsgemeinschaft Boden) elaborated and edited a position paper (policy document). This paper is titled “Consideration of natural attenuation in remediating contaminated sites” (Berücksichtigung der natürlichen Schadstoffminderung bei der Altlastenbearbeitung), state 10/12/2009. The paper hands the administrative bodies in charge practical explanations and recommendations for the implementation of NA-approaches.

The LABO document depicts the following principles:

- Natural Attenuation (NA) comprises natural reduction processes of contaminants.
- The position paper deals exclusively with NA-processes in the saturated zone.
- MNA – Monitored Natural Attenuation – are perceived to be monitoring measures to check the effectivity of natural degradation processes.
- Natural attenuation processes are site conditions, but they are not understood to be remediation measures.
- To facilitate administrative decisions, whether and how far reaching natural attenuation processes can be included in a remediation concept, the elaboration of a MNA concept is recommended. This concept should comprise in particular verifiable target definitions in space and time and measures to be taken in case of a failure of the NA targets.
- The policy document specifies measures to investigate and evaluate NA-processes as well as measures for planning and implementation of monitoring and control.

Return of experience of MNA application in Stuttgart:

The inclusion of natural attenuation processes in the design and evaluation of remediation concepts is widely accepted by the local administration in charge in Stuttgart (the municipal department for environmental protection). The experiences made indicate however that the private experts in most cases don’t follow the recommendations of the LABO position paper. The experts try to argue based on insufficient measures taken for investigation of NA processes and try predominantly to avoid urgently required remediation actions. But there are also a few cases of adequate MNA concept implementations registered in Stuttgart.

In the framework of areal approaches for the investigation of groundwater contamination natural attenuation processes were considered in Stuttgart as well. The Feuerbach groundwater investigation and modelling showed that neglecting NA in a contaminant transport model leads to an over-estimation of downstream concentrations. The inclusion of a first degree degradation was necessary to achieve an analogy of measurements and modelling results. For a more differentiated modelling of NA processes, the use of degradation milieu parameters like redox potential, nitrate and sulphate concentration is foreseen. This could lead to specific spatial NA scenarios and adequate MNA concepts.

3.4 Netherlands

Natural Attenuation has been used increasingly in recent years in the Netherlands in order to control, reduce or completely remove the risks associated with soil contamination in accordance with the provisions of the Dutch Soil Protection Act. This involves various natural processes such as chemical and biological degradation, dilution and adhesion to soil particles. As only degradation will cause a reduction in the quantity of contamination, the term Natural Attenuation only refers to actual degradation. The emphasis is on biological degradation because biological degradation processes make the largest contribution to the reduction of the contamination in the majority of cases.

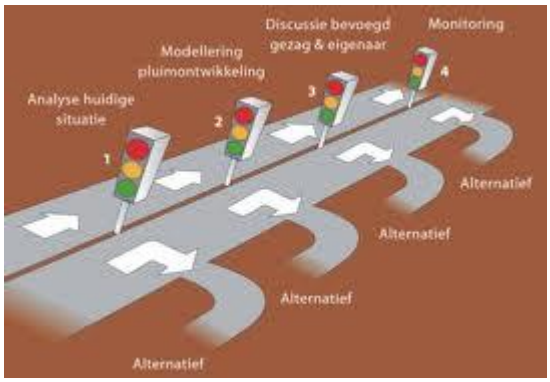


Figure 5. BOS-NA stoplight model

The decision supporting system for Natural Attenuation (BOS-NA) was developed for this purpose in The Netherlands. This systematically determines the options for Natural Attenuation as a remediation variant. The BOS-NA is expressed schematically as a road with four traffic lights (figure 1). Each of these traffic lights corresponds with a certain activity that is carried out in order to continue using Natural Attenuation as a remediation variant. It is only possible to implement Natural Attenuation when all phases (traffic lights) have been passed. When a traffic light remains red an alternative remediation variant must be considered.

The information with which the feasibility of Natural Attenuation is evaluated consists of three lines of evidence:
• demonstrable reduction of the contamination and creation of degradation products in the field;
• geochemical and biochemical indicators that indicate the occurrence of Natural Attenuation processes;
• demonstration of microbiological activity.

3.5 France

Natural Attenuation (NA) is explicitly mentioned within the French national methodology

The Ministerial “Circulaire” of February 8, 2007 mentions natural attenuation (NA) explicitly within the context of the national methodology for the management and supervision of contaminated sites and soils in France. Annex II of the Circulaire explains in some more detail the conditions for the use of natural attenuation as a management tool. The contamination has to be stabilised or has to be in regression. Furthermore, it has to be shown that the removal of the contamination is impossible or undesirable. Only when previous conditions are met and the residual levels of the contamination are in accordance with the envisioned use of the site, natural attenuation can be considered as remediation option, on the condition that it is accompanied by surveillance or monitoring.
Within the “Management Plan”, different management options (including NA) have to be considered and the choice of the best management option for the site must be justified based on a cost / benefits balance, taking into account technical, financial and environmental aspects.

A protocol to favor the real application of the NA concept

In order to eliminate bottlenecks and to favor the real application of the NA concept when relevant, the development of an operating protocol allowing the use of NA management in the French regulatory context has been recently lead, within the French project called ATTENA. This protocol has been elaborate through the contribution and expertise advice of a user group (stakeholders as administration, industrials, consultants, researchers…).

The protocol presents the way to implement NA following French regulatory. The protocol is based on a progressive, iterative, and proportional approach. The main steps of the protocol are:

- Site characterization. Evaluation of historical data and conceptual modeling are led. Sources and impacts have to be under control.
- Feasibility study of natural attenuation. Data collection and analysis for assessment of NA processes show that natural processes occur.
- Quantification of natural attenuation processes. The quantification steps include source quantification (stock), plume quantification (impact) and quantification of each NA processes: mass balance… Predictive modeling may be require (for ex. to prove the contaminants mass decrease).

  At each step, an evaluation of the results is made and decision to go-on / stop is taken. To help taking the decision to go on or to stop, some tables are prepared, gathering limiting criteria, technical and economical parameters. These tables can be used to evaluate the feasibility of MNA on a site and so if the site is a good candidate for NA implementation. After the completion of these previous steps, it must be decided whether MNA is feasible as a site management strategy. It can be implemented as a stand-alone technique or in combination with an ‘active’ technique. For this, cost and benefits have to be taken into account, as well as various possible constraints such as technical constraints, social impact, health and environmental protection, etc.
- Long term monitoring plan. The forth step of the management of the contaminated site is then - when the decision has been made to accept MNA as a management technique – to include long-term monitoring of the situation until the objectives are met.

3.6 Knowledge of “real-life” MNA projects in Europe

In spite of a few exceptions the MNA concept has obtained acceptance by regulation, technical experts and administration in Europe.

The collected information of the total amount of real-life MNA cases in practice presented in Figure may not be considered as exhaustive. Furthermore, the remark is in order that due to the heterogeneous nature of the collected information, we can’t be entirely sure about the obtained results. In particular, the status of the case (ie authority and administrative recognition or not) and/or the distinction between “ENA” and “(M)NA” and/or the fact that MNA is in combination with other (actives) techniques are not completely definite.

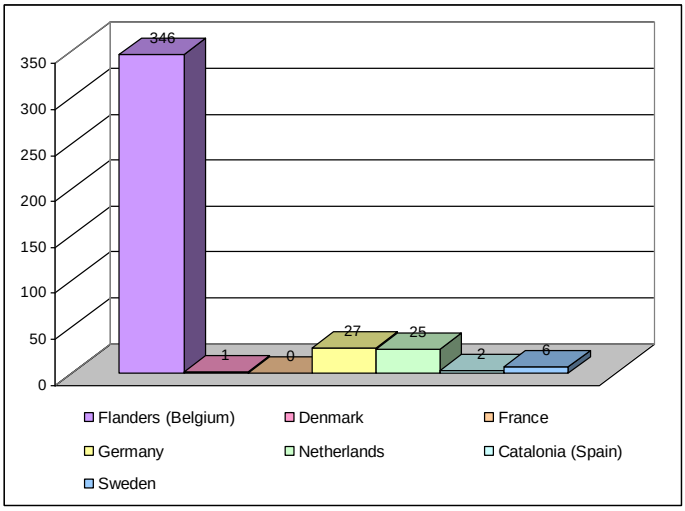


Figure 6. MNA in Europe: “real life” cases.

The collected information shows that MNA is currently being applied throughout Europe. However, there are large differences between countries, not only concerning the levels of application but also between the amounts of available information about the real-life MNA cases!

Key learning point

Concerning the application of MNA in real-life remediation projects, we can state that there are three leading countries in Europe (bearing in mind still that the number of countries included in this summary is limited): Belgium (Flanders), Germany and the Netherlands.

The feasibility of MNA depends on local circumstances and the acceptability on the national (or ever regional or local) political situation. There’s no EU wide position as MNA is a concept that covers different meaning (countries, actors …). There’s still a need to collect clear and detailed overviews of the existing MNA cases in a systematic way and to make this information publicly available.

4 MNA application in urban zones

Chlorinated solvents are amongst the most common soil and groundwater contaminants due to their widespread use as dry-cleaning solvents and degreasing agents (annex 2 of the Groundwater Directive (GWD)). Due to their physicochemical properties they produce large scale plumes of pollution in the groundwater. Pollution by chlorinated solvents is in many cases caused by small-scale activities (as dry-cleaners, garages and metal-using industry), which generated multiple contaminant sources for widespread groundwater pollution in urban areas. In the densely populated Northwestern-Europe, these pollution plumes are situated under residential and urban development areas and are therefore difficultly accessible.

Migration of volatile chemicals from subsurface soil and/or groundwater into the indoor air of overlying buildings may occur. Vapor intrusion into buildings, and subsequent inhalation, are often the main exposure pathway to humans at sites contaminated with Volatile Organic Compounds (VOCs). In such cases, the quantification of pollutant concentrations in the indoor air is essential while assessing risks for the human health. If the contaminants present in the subsurface are predicted to result in indoor air concentrations above acceptable risk levels, vapor intrusion mitigation measures should be incorporated into the design of any management option (including mitigation strategies that should be integrated into the construction of a new building). But, first and foremost, all possible means of eliminating the sources of pollution and their impacts must be sought.

Nevertheless, remediation of this type of pollution is a slow and difficult process, which is cost-intensive and exceeds in many cases the financial capacities of the polluter. A complete restoration of chlorinated solvents contaminated land and groundwater may not be achieved in (extended) urban areas at reasonable costs. The controlled use of naturally occurring degradation and retardation processes of pollutants may become the main goal.

In urban area, one of the major difficulties is to stress a clear state of subsurface contamination. Multi sources contamination localization and rank of their importance and their contribution to groundwater contaminations are not easy to perform. Intertwining plumes observation is often the situation in urban areas, with thereby frequently unknown sources. In many cases the polluters are not traceable or cannot be held liable due to the overlap of pollution plumes. Consequently, core source characterization and then source treatment are not always met in urban area (from some technical, economical and/or legal point of view).

In this context, some advantages of monitored natural attenuation (MNA) as a management option (when natural attenuation mechanisms are demonstrated to be effective) in urban zones (and mega sites) are clearly stressed (Colombano et al., 2010):
- it can be used for contaminations at great depth and under buildings
- the significant results and the reliability of results when the optimal conditions are met
- the cost advantage (and low carbon impact) in comparison to other options as active techniques
- the minimal disturbance of the soil and low impacts on the environment when using MNA.
Thus, strong point of the MNA option in urban area is the avoidance of excavation and transport of contaminated soil.

Moreover, some recent studies point out the effect of leak of waste-water and presence of other contaminants that enhance the quantity of organic carbon (electron donors) in groundwater under urban areas. The bio-degradation mechanisms for chlorinated solvent under anaerobic conditions are thus enhanced.
It must be kept in mind that MNA can be used for plume management in combination with active measures (source and plume), when relevant. MNA survey is then part of a global plan. MNA survey results may contribute to evaluate the capacity, conditions and dimensioning of bio-technical active treatment solutions. In this view, MNA is not considered as a unique solution but as a step in an area oriented approach.

Generic disadvantages and limitations of MNA are well known. Effectiveness of natural attenuation (NA) processes (which results are to reduce the mass, toxicity, mobility, volume or concentration of contaminants in soil and groundwater) are very variable, depending on site-specific aspects. In case of extended areas (whole urban area or mega-sites) difference of effectiveness of the NA mechanisms may occur in diverse zones. As NA processes are slow and thus require time to remediate contaminations, long durations are needed. Migration of contaminants when the NA-processes are slow (before they are degraded) may occur. Uncompleted degradation may also lead to the formation of (even more) toxic degradation products (for ex. VC - vinyl chloride). Uncertainties of MNA implementation to reach the assigned goal (remedial objectives, plume extension stabilisation, protection of targets …) are to be carefully evaluated.

Some classic limitation for MNA application may be not encountered or not be relevant under urban area conditions, as:
- the groundwater cannot be used during treatment
- the delay to achieve or restore a good quality of ground water mass
as those objective may not be only related to this type of contaminant (limiting use and quality of urban groundwater may not be only due to VOC contamination).

Nevertheless, MNA weaknesses may become some argument, as the slogan “contamination is part of the solution” at Utrecht location (see CityChlor area oriented approach case study). Decision making is part of a social construction. This is a reality for any management option, but it is reinforced for MNA option as it may be a long term way. Especially in urban zones, MNA option is to be carefully considered in the decision making approach with stakeholders. Social and political elements have to be taken into account as early as possible.

MNA feasibility survey requires analytical interpretations (engineering expertise). The technique requires monitoring of the dispersion of contaminants and thus quality control measures. Transparency and informing stakeholders are of importance. Comprehension of the stakes (as groundwater contamination, environmental and health risks…) and goals, but also the data and incertitude associated with any management solution (as technical, economical and legal dimensions of the situation) need to be explained and understood. Explaining and arguing for the pertinence and relevance of MNA option are to be considered within this social dimension. The MNA option survey and follow-up action (long term monitoring) constitute also in themselves, the conditions for a social approach (dialogue). This reinforces the support for administrative and public (especially residents) long term acceptance. This is indissociable from an integrated approach, with - in a urban context - a strong chapter of communication.

In summary, important aspects that should be explicitly addressed with the use of MNA concept, especially in urban zones and mega-sites, are tailored decision and investigation concepts and methods for early decision making and long-term perspective (Rügner et al., 2006).

5 MNA perspectives in Europe

Each country and each site have their specificities…

The benchmark survey has showed differences and similarities between the existing European protocols for MNA. It has been stressed that, related to the national regulatory

frameworks concerning soil remediation, approaches for the use of MNA as a contaminated land management option may be divided into two groups:
- countries where MNA is (mainly) considered within a risk-based framework, i.e. an approach that is focused on existing risks, e.g. human health-oriented contaminated land management concepts - USA, UK, France. These concepts generally focus on existing risks and do not, in most cases, define groundwater as a principle receptor.
- countries where MNA is considered (at least partly) as a concept of soil and groundwater protection - Denmark, Germany, Belgium - Flanders and Spain - Catalonia. These concepts are usually ''limit-based'', that is, groundwater in itself is regarded as the principal receptor and decision making is mainly controlled by fixed compliance criteria for groundwater.

The goal is not here to propose guidelines or recommendations for a common European MNA approach. Each protocols stress some technical steps and criteria. European regional MNA protocols have been established taking into account legal framework. The analysis of the opportunity to manage a site with MNA approach is part of national context.
Moreover, each real case is unique (geology, hydrogeology, contaminant spilling and behaviour, social-legal-financial and communication context …). Méga-site and urban environment, as they can be considered within an area oriented approach, need also specific consideration (multi source, liability, habitations, buildings …).

MNA concept has been gaining attention during the last few years. In some leader states, protocols have been established in the late 1990's, but some other member states still work on producing guidelines and protocol that fit in national methodology and legal context. We can consider that until now, MNA approach has not been applied in an extend way across Europe as a contaminated site and groundwater management option.

Application of MNA concept as option to manage sites is stressed in some European leader member states (Belgium - Flanders, Netherland, Germany). Nevertheless, MNA "real life" and long term application evaluation has not been lead and return of experience and data are not clearly available. In particular, even if some rules are established (protocols, position paper…) at a national level, administrative regional variation may occur in their application. Responsibility and decision to choose MNA as a management option seems to hold on some personal expertise and analyses. This is the effect of a not mature use of NA concept and lack of share of return of experience between all the stakeholders implied in contaminated site management.

What should be consider before using MNA as a contaminated land management option

Nevertheless, some recommendations for further improvements may be stressed, at least what may be targeted as some good practices. Before using MNA as a contaminated land management option, it must be clearly demonstrated that NA processes protect the environment from harmful impacts efficiently and persistently, which may be the case under favourable conditions mainly depending on the contaminant properties and the specific hydrogeological settings.

It has been stressed that important aspects that should be explicitly addressed are tailored decision and investigation concepts and methods for early decision making and long-term perspective (Rügner et al, 2006). A concept has been proposed by those authors to be suitable for the principle use of MNA in Europe and which is also applicable for megasites. The concept, called ROMANA (receptor-oriented multi-compartmental approach for natural attenuation) is based on scientific-technical investigations of gradually increasing

sophistication and a corresponding consecutive evaluation of the obtained results. The concept comprises the following procedural steps (Fig. 7). Let summarize it in a few sentences:

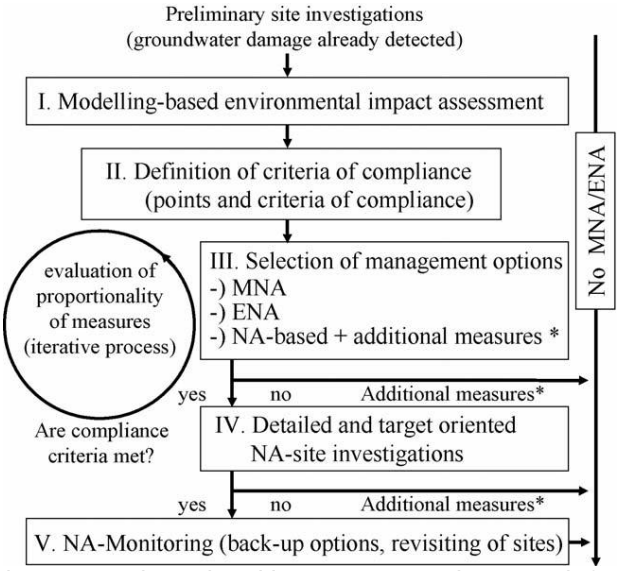


Figure 7. ROMANA (receptor-oriented multi-compartmental approach for natural attenuation)

Site investigations are conducted because groundwater damage are already detected. As a first step, a modelling-based environmental impact assessment is performed. Prediction of contaminant spreading, assessment of possible contaminant input into final sinks, identification of presumably relevant receptors (existing and future land use and spatial planning objectives have to be considered) and assessment of impacts (over time) on the relevant receptors are established.

Based on the results of the environmental impact assessment, points of compliance (POC) and corresponding compliance criteria are to be determined by the regulating authority at a very early stage of the investigation programme. These targets may be reconsidered later on if subsequent steps reveal that one or more criteria cannot be met by proportionate means (i.e., none of the available remediation options will achieve the goals at reasonable costs).

Here, suitable management options are selected, on the grounds that they are able to conform to the previously defined criteria. NA-based management options include MNA, ENA (enhanced natural attenuation) or any combination of MNA/ENA and other measures (technical measures and/or restrictions/changes concerning land use). For performance assessment of management options the modelling approaches developed during the environmental impact assessment may be used.

If MNA/ENA (unassisted or in combination with other measures) are estimated to represent possible management options, detailed NA investigations are performed.

Subsequently, a monitoring programme and/or follow-up/back-up management options are defined. This includes the time, locations and techniques of control measurements to prove that the defined requirements are fully met. For the case that monitoring reveals that NA processes do not perform as predicted, back-up management options according to the requirements of the regulating authority needs to be defined.

What should be stressed in the ROMANA concept as suitable for mega-site or urban environment cases are:

- an increased emphasis on modelling (conceptual site model, environmental impact assessment, points of compliance and criteria)
- iterative and proportional consideration
- evaluation and reconsideration of any option
- consideration of MNA in combination with other technical measures and/or restrictions/ changes concerning land use.

Enhance MNA application, acceptance and experience

Decision making is also part of a social construction. Protocols, technical tools, catalogue criteria are essential to reinforce confidence with authorities and to guide the decision. Choice of MNA option to manage a polluted site relies on the quality of survey in order to prove its feasibility. Scientific and technical data and proof of evidence need to be clearly available for expertise evaluation and for communication plan.
As for any management option, incertitudes are part of MNA use and results. Every technical criteria should not be translated into strict obligation. Simplifying acceptance catalogue could help for MNA option choice communication for the public on technical questions.
Dissemination and acceptance of MNA concept will rely on the robustness and transparency of decision making process on real cases and the condition of application (i.e. long term monitoring), in order MNA not to be considered as an “inaction” option. De facto, information, formation, communication are of great importance between every stakeholders.

Until now, MNA approach has not been applied in an extend way across Europe. It’s partly due of a not mature use of NA concept and a lack of (application and long term) evaluation. Understanding the pros and cons, difficulties and bottlenecks but also success stories (reason, factor of success) is then of importance in order to progress, especially for complex situations as megasite and urban environment. This benchmark is not intended to unify European concepts, approaches and practice. It may lead to evolve understanding of the MNA concept and to enhance acceptance by stakeholders. Return of experience between actors involved in decision making in the field of contaminated sites will favor MNA concept to encounter a real place (when relevant).

Innovation still runs and new concepts and cost effective tools adapted to site specific situations to prove and to assess NA mechanisms are to be continuously investigated. Sharing information and knowledge must include those methodological and technological evolutions. Evaluation of available tools (which are not exclusive of NA concept) and their application into practice for MNA demonstration or linked with other option (as enhanced natural attenuation) are required. This may be lead with extra national dimension, especially at European level, to favor best practices, in accordance with specific national rules if any.

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KORA Kontrollierter natürlicher Rückhalt und Abbau von Schadstoffen bei der Sanierung kontaminierter Grundwässer un Böden; Retention and Degradation Processes Reducing Contaminants in Groundwater and Soil (research project) http://www.natural-attenuation.de/

UBA UmweltBundesAmt - (Federal Environment Agency) http://www.umweltbundesamt.de/index-e.htm.

ITVA Ingenieurtechnischer Verband Altlasten e.V. http://www.itv-altlasten.de/

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