SNOWMAN NETWORK
Knowledge for sustainable soils

State of the art concerning MNA in Europe – Germany

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

Revised version

Inge Declercq

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1. Regulation and status

1.1. Regulatory context

Soil regulation in Germany, which includes the prevention and post-contamination protection of the soil and treatment of polluted sites, is organised within the Bundes-Bodenschutzgesetz - the Federal Soil Protection Act - from 17 March 1998 and the Bundes-Bodenschutz- und Altlastenverordnung - Soil Conservation and Contaminated Site Ordinance – from 12 July 1999.

Concerning the topic of natural attenuation, a position paper was released for publication by the circular resolution (number 17/2005) of the conference of Environment Ministers in 2005. This position paper was recommended to the German Region States for application. The position paper was then adjusted in 2009 in order to take into account the results from the KORA[1] research program. It includes among other things definitions of (monitored) natural attenuation ((M)NA), the relation between NA and German soil protection law, requirements and considerations for implementation of MNA and a potential approach to the use of MNA in practice. The position paper by LABO (Bund/Länder-Arbeitsgemeinschaft Bodenschutz or the Federal State Working Group on Soil Protection) only takes into account the NA in the saturated zone.

The position paper[2], which was translated into English in 2011, places the use of MNA within the regulatory context and hereby refers to several articles from the Federal Soil Protection Act (or BBodSchG):

- Art.2 (8) concerning the definition of protection and restriction measures;
- Art.4: obligations to prevent hazards, (3), (5) & (6);
- Art.9: risk assessment and orders for investigation, (2);
- Art.10 (1) concerning justified rejection of orders;
- Art.13: investigation and planning for remediation, (1);
- Art.15: supervision by authorities and self-monitoring, (2).

It also refers to some articles from the Federal Soil Protection Ordinance (or BBodSchV):

- Art.3 (7) concerning investigations;
- NA processes are part of the relevant site conditions that have to be evaluated according to Art.4: obligations to prevent hazards, (1) & (4);
- Art.2 (3) concerning the definition of an 'exploratory investigation'.

In Figure 1, it is shown how natural attenuation could be included in the gradual remediation of contaminated sites and groundwater damages, based on the articles listed above and as suggested in the position paper.

However, until now, German law does not foresee NA as a remediation measure, seeing that it is not in full accordance with legislation. The federal Environment Agency UBA expects that the next update of the legal framework will include NA as well. (J. Frauenstein, personal communication, 9 September 2011)

[1] KORA stands for Kontrollierter natürlicher Rückhalt und Abbau von Schadstoffen bei der Sanierung kontaminierter Grundwässer und Böden.
[2] As discussed in paragraph 3.3.

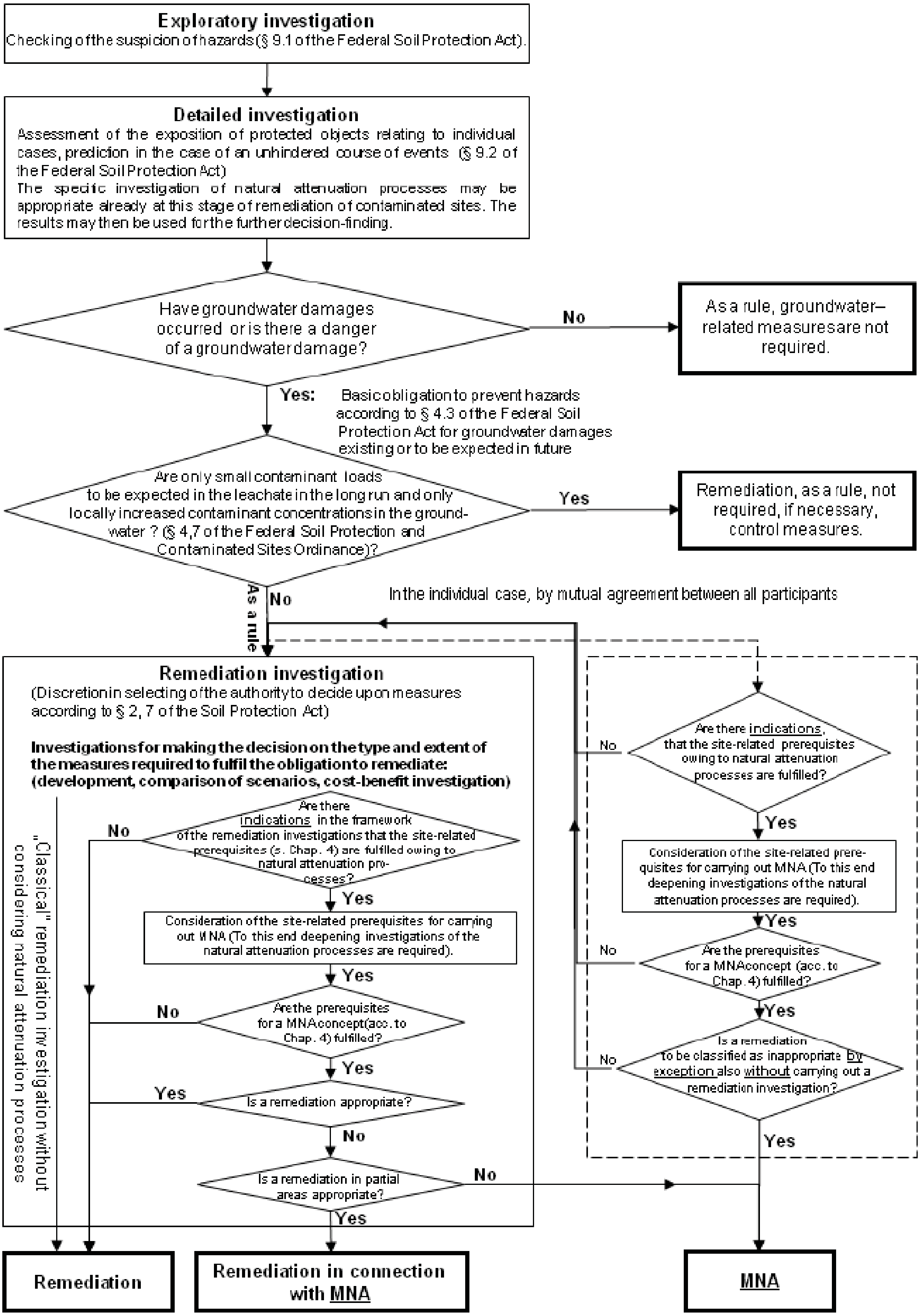

Figure 1. Pathway representing the remediation of contaminated sites and groundwater damages in Germany: consideration of MNA. (LABO, 2011, p.9)

1.2. Status

1.2.1. Contaminated sites in Germany

An inventory on contaminated sites in Germany is available on the UBA website (UmweltBundesAmt). The same numbers can be found in a LABO publication (2011b). The data holding the German status of July 2011 is summarised in Table 1. It shows that approximately 315.000 sites are suspected as being contaminated, the contamination was confirmed for about 14.000 sites. Approximately 3800 sites fall under the category "Under supervision/monitoring". As defined in paragraph 1, article 15 from BBodSchG, "monitoring" has to be performed on contaminated sites or on sites suspected of contamination; it is possible that this includes self-monitoring. From correspondence with the UBA, it can be assumed that this monitoring includes the following of NA-processes. (J. Frauenstein, personal communication, 9 September 2011)

Table 1. Contaminated sites in Germany – status 2011.

	suspected sites	**contaminated sites (confirmed)**	**finalised remediation**	**finalised risk assessment**	**ongoing remediation**	**contaminated sites under monitoring / supervision**
Baden-Württemberg	13840	2219	2624	15228	620	435
Bayern	16795	1051	1658	5088	966	85
Berlin	5885	937	191		71	72
Brandenburg	19738	1476	4073	4279	131	234
Bremen	3557	408	621	951	42	167
Hamburg	1828	533	426	3093	147	140
Hessen	1040	436	880	1922	236	51
Mecklenburg-Vorpommern	5835	999	1155	267	359	396
Niedersachsen	93825	3482	1597	4714	381	535
Nordrhein-Westfalen	75370		6158	17969		
Rheinland-Pfalz	12497	296	128	6516	168	58
Saarland	1973	456	156	379	35	64
Sachsen	19785	627	2927	6638	434	1474
Sachsen-Anhalt	16682	186	1680	3662	71	50
Schleswig-Holstein	13781	320	974	2472	66	54
Thüringen	12570	783	837	4506	191	71
Total	**315001**	**14209**	**26085**	**77684**	**3918**	**3886**

1.2.2. NA in research: locations in Germany

Within the context of research[3], several sites in Germany have been studied for their natural attenuation ability. A few examples are the 23 sites in the KORA project (2002-2008) and the five model sites of the joint project of the GAB (Gesellschaft zur Altlastensanierung in Bayern mbH; 2001-2003).

One of the best known German sites for research on NA is the megasite Zeitz near Leipzig which is contaminated by monocyclic, polycyclic and aliphatic hydrocarbons (PAH) and where BTEX (benzene, toluene, ethylbenzene and xylene) are found in the aquifer. Among other research projects, RETZINA studied several methods to demonstrate NA. (Fischer et al., n.d.; Wachter & Dahmke, n.d.) The megasite of Zeitz is also discussed in several scientific articles such as those of Schirmer et al. (2006); Vogt et al. (2007) and Hirsch (2009).

[3] The NA-research projects KORA, GAB and RETZINA will be discussed in paragraph 2.2.

Another site that has been studied several times for its natural attenuation capacity is a location in the Bitterfeld/Wolfen area (south of Berlin). Scientific publications on the NA-processes of Bitterfeld are e.g. those of Heidrich, Weiß & Kaschl (2004) and Nijenhuis et al. (2007).

Other sites in Germany were found where natural attenuation was studied as well. For example: Vieth et al. (2003) studied a former dry-cleaning plan in Leipzig; Hornbruch, Schäfer & Dahmke (2005) performed modelling of NA-processes at a former coking plant; Licha & Sauter studied the NA potential of 12 test sites through tracer tests; Martienssen et al. (2005) studied a chemical plant site in Leuna for the occurrence of attenuation of MTBE (methyl tertiary butyl ether); multiphase modelling of a site in Niedergörsdorf was done by Miles, Peter, Sudicky, Maji & Teutsch (2005) and the MonteScherbelino landfill was modelled by Spinola, Gerdes & Kämpf. The scientific paper by Micic, Straub, Blum and Kappler (2007) describes how they demonstrated the possibility of MNA as an alternative strategy for remediation at a former gasworks site in Southern Germany.

A non-exhaustive overview of German sites in (M)NA research is given in Table 2 below. If information about the chosen management approach for the contaminated site was available in the consulted documents; the consideration of MNA for remediation is indicated ('n.a.' marks the documents where no information was available and the chosen technique for remediation).

Table 2. Overview of German sites in research.

Research	***Location(s)***	***NA?***	***MNA?***
KORA research project	23 sites	Yes	
GAB joint project	5 sites	Yes	
RETZINA research project Alfreider & Vogt (2007) Vogt et al. (2007) Hirsch (2009)	Zeitz megasite	Yes	MNA is considered to manage existing contamination plumes
Wycisk, Weiss, Kaschl, Heidrich & Sommerwerk (2003) Heidrich, Weiß & Kaschl (2004) Heidrich et al. (2004) Nijenhuis et al. (2007)	Bitterfeld/Wolfen	Yes	MNA can only be an employed as a complementary strategy to other active remediation measures
Licha & Sauter (n.d.)	12 test sites	Yes	n.a.
Spinola, Gerdes & Kämpf (n.d.)	MonteScherbelino landfill	Yes	n.a.
Zamfirescu & Grathwohl (2001)	Former gasworks site in Neckar	Yes	n.a.
Vieth et al. (2003)	Former dry-cleaning plant in Leipzig	Not clear	n.a.
Hornbruch, Schäfer & Dahmke (2005)	Former coking plant	Yes	n.a.
Martienssen et al. (2005)	Leuna chemical plant	Yes	n.a.
Miles, Peter, Sudicky, Maji & Teutsch (2005)	Site in Niedergörsdorf	Yes	n.a.
Micic, Straub, Blum and Kappler (2007)	Former gasworks site in Southern Germany	Yes	The authors conclude that in order to be able to implement MNA the monitoring network has to be expanded.

1.2.3. Use of MNA as a remediation method

A general database which collects information concerning applied remediation techniques in Germany does not exist. This is due to the fact that the responsibility to finance the remediation projects in Germany lies with different parties. (J. Frauenstein, personal communication, 9 September 2011) So, in order to get an idea of the application of MNA in Germany, the search for information was focussed on the different regions or "Länder".

- *Baden-Württemberg*

For the region of Baden-Württemberg, a presentation of the "Working with Nature" symposium of April 2010 mentions that fifteen sites (Table 3) in the region of Baden-Württemberg included the application of MNA since 2004. Two of the fifteen fall within the framework of the KORA research project, so that leaves thirteen real-life cases. For one of these thirteen locations (the gasworks site Kehl), the site was partially remediated with other measures than MNA. There are four sites where the MNA is already being applied; seven where it has been (legally) approved; one where MNA is in consideration and one where the NA-processes are being evaluated. (Kohler, 2010)

Table 3. Real-life MNA-projects (not in research) in Baden Württemberg since 2004.

	Location	Contaminants	Status
1	Waste deposit site Osterhofen, Ravensburg	ammonium	Approved
2	Waste deposit site Seehof, Ettlingen	ammonium	Approved
3	Röschenwasser	ammonium	Approved
4	Waste deposit site Cattunlache,Offenburg	ammonium	In consideration
5	Gasworks site Kehl	PAH	Approved
6	Waste deposit site Untere Neue Wiesen, Wernau	PAH, heavy metals, highly volatile chlorinated hydrocarbons	Approved
7	Gasworks site Endingen	PAH, BTEX, cyanide	MNA applied
8	Gasworks site Reutlingen	PAH, heterocyclic compounds, BTEX, cyanide, ammonium	MNA applied
9	Gasworks site Esslingen		MNA applied
10	Ehem. Nato-Flugplatz Bremgarten	mineral oil hydrocarbons, BTEX	Approved
11	Weinheim	highly volatile chlorinated hydrocarbons	Approved
12	Stürmlinger Sandgrube, Karlsruhe	PAH, BTEX, heterocyclic compounds	NA-investigations
13	Waidweg, Karlsruhe	PAH, mineral oil hydrocarbons	MNA applied

Rügner et al. (2004a) described the NA-related investigations for the former gasworks site "City of Kehl". The groundwater at this location is contaminated by PAH. Based on the performed investigations, the assessment committee for contaminated sites ruled that the application of active remediation measures would be lifted and instead, they would rely on MNA for the management of the contaminated site. A monitoring plan was drafted.

Another case where MNA is found to be an appropriate land management option in Baden-Württemberg is also discussed by Rügner. The location is a former municipal landfill site called Osterhofen where the groundwater is contaminated by ammonium. It is mentioned that the MNA concept is imaginable as a remediation measure because it is more in proportion to the contamination than other cost-intensive remediation measures. (Rügner et al., 2004b)

An example from the slide show presentation by Söhlmann of the "Working with nature" symposium discusses the site of Reutlingen where NA conditions are favourable, but monitoring is needed in order to assure the sustainability of the NA-processes. (Söhlmann, 2010)

- *Bayern*

Information on MNA projects was found for Bayern, also in a presentation from the "Working with Nature" symposium. Up till April 2010, seven projects were registrated; MNA was performed for five cases because the remediation of the residual contamination was found "disproportionate"; MNA was chosen twice because other remediation measures were impossible or "disproportionate". Furthermore, it is mentioned that one project is in the application phase; four are in the planning phase and MNA is applied for all sites in the combination with other remediation measures. The presentation includes a case study in München. (Rüttinger, 2010)

- *Berlin*

Examples of soil remediation projects in Berlin are available on the Länder website. From these examples, seven projects mention the use of monitoring; two other remediation projects speak specifically of enhanced natural attenuation (ENA) and only one is based on the application of MNA. The site “Tanklager Staatsreserve" is contaminated by BTEX and PAH. Active remediation of the groundwater took place between 1997 and 2001; in 2001-2002 excavation of part of the contaminated soil was executed. There is a residual contamination which is managed through MNA. (Website Berlin)

Besides this one example, further information on the choice of MNA as a remediation technique in Berlin was not found online.

- *Brandenburg*

A publication describing the environmental data for Brandenburg for the period of 2008-2009 mentions that in the region of Brandenburg 33 sites are being monitored continuously to investigate and assess changes of soil quality. (LUA, 2009) However, no information was found on the use of MNA in Brandenburg.

- *Bremen*

In the Bremen region there are 34 old deposit sites being monitored under the AÜP program (Überwachungsprogramms für Altablagerungen in der Stadtgemeinde Bremen 2006). The groundwater is being monitored at all sites, the earliest monitoring started in 1992. As explained, the natural attenuation processes are part of the monitored parameters. (Der Senator für Bau, Umwelt und Verkehr, 2006)

Information concerning current knowledge of groundwater contaminations in Bremen can be found in a publication from 2006. This publication discusses among other things the possible groundwater remediation methods; e.g. the possibility to enhance natural degradation for decontamination. The publication emphasises that these enhanced natural attenuation processes cannot be used as a stand alone technique, but only as an additional technique. MNA is included in the measures to prevent the spreading of the contamination (without decontamination). (Der Senator für Bau, Umwelt und Verkehr, 2006b)

Numbers on the use of MNA in Bremen were not found.

- *Hamburg*

On the website of the region of Hamburg, it is mentioned that 146 sites are being monitored (which is more than indicated in Table 1). However, no information was found on the use of MNA. (Website Hamburg)

- *Hessen*

Statistics for MNA-application were found in the “Altlasten Annual 2010” for the region of Hessen. This publication mentions that in-situ techniques for soil remediation have gained interest in the last few years. Furthermore, it is shown that the application in practice of those techniques has increased as well: for the region of Hessen (in the period 2002-2008) a total of eighteen in-situ measures were taken for the remediation of groundwater, five of which concern the use of the MNA technique[4]. In comparison: for the period of 1996-2001, three in-situ measures were taken for groundwater remediation. For the period of 2002-2008; the in-situ techniques present 2,3% of the total remediation measures for soil and groundwater, compared to 0,5% for the period of 1996-2001. (HLUG, 2011)

[4] The other measures were: biological in-situ techniques (#:five) such as the injection of micro organisms and chemical-physical in-situ remediation of groundwater (#: eight).

Two examples, discussed by Wüstemann and Widman, were found in the “Altlasten Annual 2007” from HLUG which was published in 2008.

The first example from HLUG includes the use of conventional remediation methods for soil and groundwater contamination at a site in Kassel (from Esso AG; in North Holland), followed by MNA measures. The decision to use MNA was based on the criteria from the HLUG guidebook (as discussed in paragraph 3.4). There were difficulties to get the MNA project approved by all parties due to the long duration of the project and the required patience to obtain results. The active remediation was finished in 2003; five years of MNA followed. Results showed that patience will be required, since the measurements didn’t show a strong reduction of the contamination. (Wüstemann, 2008)

The second example from HLUG also combines traditional remediation measures with MNA. The project site was a PAH contaminated factory in Hanau. The HLUG guidebook was used to decide on the application of MNA but based on this, MNA was rejected. After the performed feasibility study in 2005-2006, it was decided to apply MNA downstream of the source area. (Widman, Karg, Hintzen, & Portune, 2008)

- *Mecklenburg - Vorpommern*

On the Mecklenburg-Vorpommern website, it is mentioned that the corrective actions concerning contaminated soils include the detection, remediation and monitoring of those sites. The website offers the same information concerning contaminated and remediated soils as presented in Table 1; however, no information on the choice of MNA as a remediation technique was found. (Website Mecklenburg-Vorpommern)

- *Niedersachsen*

The website of Niedersachsen mentions the existence of a long-term monitoring program (“Langzeitprojekt des Niedersächsischen Boden-Dauerbeobachtungsprogramms”) since 1991 which registrates changes in the soil. (Website Niedersachsen) No information was found on MNA in the Niedersachsen region.

- *Nordrhein – Westfalen*

The chapter on soil protection from the 2009 environmental report for the region of Nordrhein-Westfalen mentions that information on suspected contaminated locations has been collected since 1979. Furthermore, the document holds statistics on soil remediation. For example: more than 6000 remediation actions were taken (from 2006 on) for 4211 locations; which means that for most sites multiple measures were taken. Furthermore, the publication mentions that in-situ biological methods (ENA) are used (seventeen for 2009) for groundwater remediation. Also mentioned is the rapid increase in the use of such methods[5]. The publication also discusses MNA as a remediation technique, but no specifications were given other than “the first MNA-concepts in the Nordrhein-Westfalen region will be performed”. (MUNLV, 2009)

- *Rheinland - Pfalz*

No information was found on the application of MNA for the Rheinland-Pfalz region.

- *Saarland*

The website of the Saarland region mentions the long-term monitoring of eleven sites. However, no information was found on the choice of MNA as a remediation technique in Saarland. (Website Saarland)

- *Sachsen*

No numbers were found on the use of MNA.

[5] In comparison: in the Umweltbericht from 2006; only five biological ENA projects are mentioned. (MUNLV, 2006)

- *Sachsen-Anhalt*

The website of Sachsen-Anhalt mentions the same numbers as Table 1 for the statistics on contaminated and remediated sites in the region. Furthermore, 68 sites are under long-term monitoring. No information was found on the application of MNA. (Website Sachsen-Anhalt)

- *Schleswig-Holstein*

The website offers charts of the region with relevant statistics concerning soil remediation projects, but no information was found on the choice of MNA as a remediation method. (Website Schleswig-Holstein)

- *Thüringen*

In the environmental data section ("Umweltdaten" for 2011) of the website of the Thüringen region, the same numbers concerning soil remediation are available as the ones presented in Table 1. Further information is available on the application of monitoring: there are 32 sites within the region of Thüringen that fall under long-term monitoring since 1992. (TLUG, 2006) Concerning natural attenuation, the website mentions that currently an evaluation is being performed of the research projects (from KORA) which experience concerning this topic. However, no further information was found on the application of MNA in the Thüringen region. (Website Thüringen)

Another "real life" example of MNA which isn't included in the statistics found for the different regions was found online. The groundwater of the former military airfield Wegberg-Wildenrath (Nordrhein-Westfalen) is contaminated by petroleum hydrocarbons. In 1995, a remediation plan was drawn up for the site and several active measures were performed. To guarantee remediation on the long term, MNA was introduced. Monitoring has been performed for at least 10 years. (Website HYDR.O. Geologen und Ingenieure)

Table 4. Applied MNA projects in Germany: information found online.

Region	***Contaminated sites: #***	***Finalised remediation: #***	***MNA projects: #***	
Baden-Württemberg	2219	2.624	13	2004-2010
Bayern	1051	1.658	7	Until April 2010
Berlin	937	191	1	2002
Hessen	436	880	5	2002-2008
	4643	**4213**	**26**	
+ *Wegberg-Wildenrath*				
Total			**27**	

Summarising the previous findings, concrete statistics on the use of MNA as a remediation method were found only for the regions Hessen, Bayern and Baden-Württemberg. Project examples where MNA is applied was found for Berlin and for Wegberg-Wildenrath. Table 4 lists an overview per Länder of those remediation projects where MNA was chosen as part of the remediation technique; as well as the additional example found online. The integral answer to the question concerning the application of MNA in Germany remains partly unanswered. Possibly, MNA is applied in other Länder as well, such as in the region of Nordrhein-Westfalen; however, no such information could be retrieved through online research. Thus: application of MNA in Germany is limited and the level of application is very different between individual regions! Furthermore, the statistics of the Hessen region demonstrate that the application of MNA has increased over the last years. (HLUG, 2011)

Additionally, in a presentation by M. Bittens at the SNOWMAN workshop on MNA (November 7th, Paris) it was mentioned that, according to a survey of the German Bundesländer, over a 100 MNA cases have been notified by local agencies. (Bittens, 2011)

2. Documents and projects

This document listing includes regulatory outlines, documents on NA-research projects, methodologies and protocols.

2.1. Existing Documents

2.1.1. Regulatory outline of soil protection (1998-1999)

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. (1998). *Federal Soil Protection Act of 17 March 1998 (Federal Law Gazette I, p.502) - Translation*. Bonn: Federal Government.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. (1999). *Federal Soil Protection and Contaminated Sites Ordinance dated 12 July 1999 - Translation*. Germany: Federal Government.

2.1.2. RETZINA project

The joint research project RETZINA (Reference Test Site Zeitz for the Implementation of the Natural Attenuation approach; 2000–2003) aimed to develop methods for the quantification of NA-processes in groundwater.

Schirmer, M., Dahmke, A., Dietrich, P., Dietze, M., Gödeke, S., Richnow, H., Schirmer, K., Weiß, H. & Teutsh, G. (2006). Natural attenuation research at the contaminated megasite Zeitz. *Journal of Hydrology* (328), pp.393-407.

2.1.3. GAB joint research project (2001-2003)

The Gesellschaft zur Altlastensanierung (GAB) in Bayern managed a joint project through the years 2001-2003 concerning natural attenuation, which is discussed in paragraph 2.2.2.

GAB. (2004). *Bayerisches Forschungsverbundvorhaben "Nachhaltige Altlastenbewältigung unter Einbeziehung des natürlichen Reinigungsvermögens" - Zusammenfassende Darstellung der Ergebnisse und Erkenntnisse der Teilprojekte 1 bis 6*. München: GAB.

2.1.4. KORA funding project (2002-2008)

This research program (paragraph 2.2.3) resulted in a “recommendation for action” as well as six “Leitfaden” or guidelines concerning topics related to NA, as listed below (paragraph 3.2). The documents include e.g. detection methods and evaluation approaches for individual attenuation processes.

- Theme 1: natural attenuation processes in sites contaminated by mineral oil;
- Theme 2: natural pollutant attenuation in the case of tar oil loads;
- Theme 3: natural pollutant attenuation processes in sites contaminated by HCHC;
- Theme 4: dealing with groundwater damages caused by waste deposits and hazard situations considering the effects of natural retention and degradation processes;
- Theme 5: natural pollutant attenuation in explosive-typical compounds;
- Theme 6: natural pollutant attenuation processes in mine dumps and sediments in river meadows.

Michels, J., Stuhrmann, M., Frey, C. & Koschitzky, H.P. (2008) *Handlungsempfehlungen Natürliche Schadstoffminderung bei der Sanierung von Altlasten - Bewertung und Anwendung, Rechtliche Aspekte, Wirtschaftlichkeit und Akzeptanz mit Methodensammlung*. Frankfurt am Main: DECHEMA e.V.

Wabbels, D. & Teutsch, G. (2008). *Leitfaden Natürliche Schadstoffminderungsprozesse bei mineralölkontaminierten Standorten – Methoden, Empfehlungen, und Hinweise zur Untersuchung und Beurteilung. KORA Themenverbund 1: Raffinerien, Tanklager,* *Kraftstoffe/Mineralöl, MTBE*. Tübingen: Universität Tübingen, Zentrum für Angewandte Geowissenschaften (ZAG).

Werner, P., Börke, P. & Hüsers, N. (2008). *Leitfaden Natürliche Schadstoffminderung bei Teerölaltlasten. KORA Themenverbund 2: Gaswerke, Kokereien, Teerverarbeitung, (Holz-)Imprägnierung.* Pirna: Technische Universität Dresden, Institut für Abfallwirtschaft und Altlasten.

Grandel, S. & Dahmke, A. (2008). *Leitfaden Natürliche Schadstoffminderungsprozesse bei LCKW-kontaminierten Standorten - Methoden, Empfehlungen, und Hinweise zur Untersuchung und Beurteilung. KORA Themenverbund 3: Chemische Industrie, Metallverarbeitung.* Kiel: Christian-Albrechts-Universität zu Kiel, Institut für Geowissenschaften, Abt. Angewandte Geologie.

Luckner, T. & Luckner, L. (2008). *Leitfaden Umgang mit abfallablagerungsverursachten Gewässerschäden und Gefahrensituationen unter Berücksichtigung der Wirkungen naürlicher Rückhalte- und Abbau-Prozesse – KORA Themenverbund 4: Deponien, Altablagerungen.* Dresden: Dresdner Grundwasserforschungszentrum e.V.

Joos, A., Knackmuss, H.J. & Spyra, W. (2008). *Leitfaden Natürliche Schadstoffminderung bei sprengstofftypischen Verbindungen – Prozessverständnis, Methoden, Referenzstandorte, Empfehlungen und Hinweise zur Einzelfallbearbeitung. KORA Themenverbund 5: Rüstungsaltlasten*. Berlin: IABG mbH.

Hoth, N., Rammlmeir, D., Gerth, J. & Häfner, F. (2008). *Leitfaden Natürliche Schadstoffminderungsprozesse and Bergbaukippen/-halden und Flussauensedimenten – KORA Themenverbund 6: Bergbau und Sedimente, Sauerwasser, Schwermetalle, HCH und DDX*. Freiberg: Technische Universität Bergakademie Freiberg, Institut für Bohrtechnik und Fluidbergbau (IBF).

2.1.5. ITVA “Arbeitshilfe” (2004)

In 2004, ITVA (Ingenieurtechnischer Verband Altlasten e.V.) published a guidebook (cfr. Paragraph 3.1) concerning the implementation of MNA in accordance with German law.

ITVA. (2004). *Arbeitshilfe Monitored natural Attenuation*. Berlin: ITVA.

2.1.6. Position paper (2005)

The consulted paper is a translation of the original version from 2005, drafted in April 2011. It includes adjustments based on information from the KORA project (2009). The content of the position paper is discussed in paragraph 3.3.

LABO. (2011). *Consideration of natural attenuation in remediating contaminated sites – position paper of 10/12/2009*. Germany: Umweltbundesamt.

2.1.7. HLUG “Arbeitshilfe” (2005)

In 2004, the HLUG (Hessiches Landesamt für Umwelt und Geologie) published the “handbook of environmental contaminations“ (volume 8). The second edition was published in 2005. The first part of this handbook concerns the concept of MNA and possibilities for implementation. The second part deals with the management of possibly contaminated land and sites in Germany, which also mentions MNA. This guide is discussed in paragraph 3.4.

HLUG. (2005). *Handbuch Altlasten, Band 8, Teil 1 - Arbeitshilfe zur Überwachten natürlichen Abbau - und Rückhalteprozessen im Grundwasser (Monitored Natural Attenuation MNA)*. Wiesbaden : HLUG.

HLUG. (2005). *Handbuch Altlasten, Band 8, Teil 2 - Arbeitshilfen zur Überwachung und Nachsorge von altlastverdächtigen Flächen und Altlasten*. Wiesbaden : HLUG.

2.1.8. Manual for the use of biological remediation techniques (2006)

In 2006, the International Centre for Soil and Contaminated Sites (ICSS) published a manual concerning the use of biological remediation techniques. The publication includes a description of the MNA-concept; prerequisites for application and elements of the MNA approach; advantages and disadvantages of application. It also offers a decision-making matrix for the application of MNA and other remediation techniques. This decision matrix will be discussed in paragraph 3.5.

ICSS. (2006). *Manual for biological remediation techniques*. Dessau, ICSS.

2.2. Research projects

2.2.1. RETZINA project

The joint research project RETZINA was started in 2000 and concluded in 2003. The aim was to develop methods for the quantification of NA-processes in groundwater. The test site in the project was the former hydrogenation plant Zeitz. The project included data collection through point measurements; reactive multi-tracer tests; stable isotope measurements; modelling and toxicological long term monitoring. (Schirmer et al., 2006; Project Website)

2.2.2. GAB joint project

The GAB managed a joint project concerning the "Natürlichen Reinigungsvermögens" or natural attenuation abilities of five model sites called "Sustainable remediation of contaminated sites by incorporating natural attenuation". This research project took place during the period 2001-2003 and aimed to gather information concerning the possible implementation of MNA for the remediation of contaminated sites. The project included several model sites (or "Teilprojekte"), each selected for their contamination by one of the most significant contaminating compounds: PAH, highly volatile chlorinated hydrocarbons (HVCHC), mineral oil hydrocarbons, arsenic and copper. Figure 2 shows the positioning of the model sites in Germany.

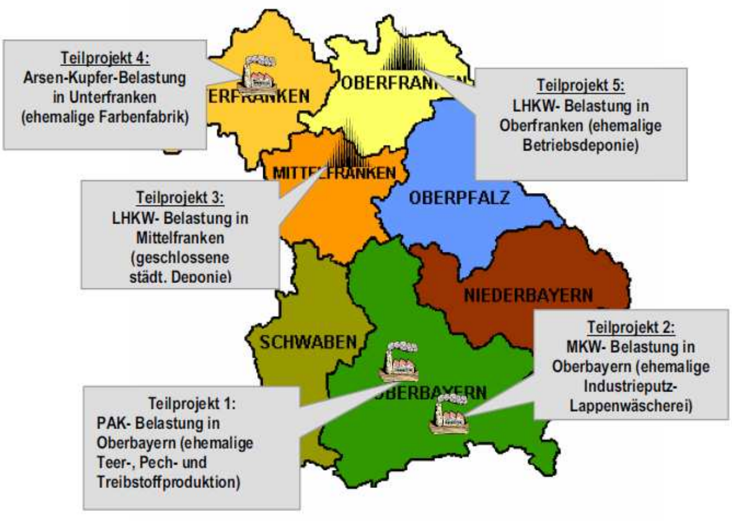

Figure 2. Joint research project from the GAB (2001-2003): overview of the model sites in Germany. (GAB, 2004, p.7)

2.2.3. The Funding priority KORA

The KORA project of the Federal Ministry of Education and Research (the Bundesministerium für Bildung und Forschung or BMBF) - Retention and Degradation Processes Reducing Contaminants in Groundwater and Soil - started in 2002 and lasted until 2008. It was prepared and managed by two project management organisations (the Project Agency for Water Technology and Waste Management and the Project Agency Jülich, for environmental projects). The objective of this research was to investigate intrinsic retention and degradation processes of contaminated sites, which lead to a reduction of contaminants in groundwater and soil. The ultimate aim was to develop guidebooks, technical and legal instruments to facilitate the use of MNA as a remediation tool. (Michels, Wachinger & Franzius, n.d.)

On the official website of the KORA project, a map of Germany is presented featuring the 23 sites that were part of the KORA project. It is represented in Figure 3 and as shown, contaminants on those 23 sites were mineral oil (yellow); tar oil (black); chlorinated discharge substances (green); damages caused by waste deposits (blue); explosives (red) and heavy metals (grey).

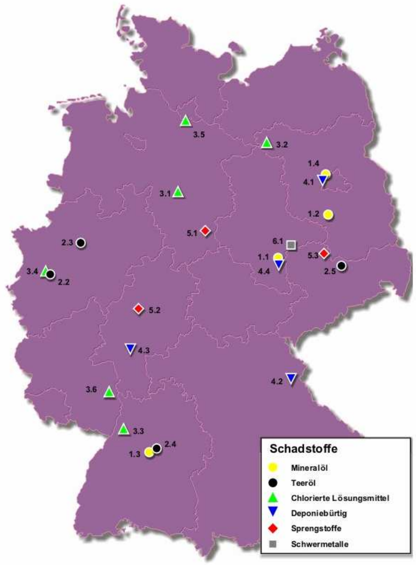

Figure 3. The KORA sites and their contaminants.

3. Guidebooks and methodologies

3.1. ITVA

The publication of 2004 includes an overview of how MNA can be implemented according to German law. Considering the primary importance of the LABO position paper, which makes a similar contemplation, is more recent and makes recommendations for practical use of MNA, it will not be discussed here any further. (ITVA, 2004)

3.2. KORA

The KORA funding project, as stated above, resulted in both recommendations for actions and six guidebooks concerning specific topics. These documents were not found in the English language so for further information consultation of the German documents is advised.

3.3. LABO Position Paper

3.3.1. Recommendations for approaches in practice

The first annex of the position paper (2011) describes in detail the different steps needed for the practical remediation of contaminated soils by using MNA. The recommendation is presented in Table 5. It contains the following basic steps:

1. Evaluation of prerequisites
    a. Targets set by authority
    b. Checking of the site-related prerequisites according to present knowledge
2. Investigations to prove the effectiveness of NA processes
    a. Site investigations to proof the effectiveness of NA processes
    b. Prediction of the development of the plume
    c. Evaluation and assessment of results
    d. Preparation of a MNA concept
3. Administrative decision to implement MNA
4. Carrying out MNA

Table 5. Recommendation for the implementation of a MNA concept (LABO, 2011, p.19)

Ist step	Checking of the prerequisites for preparing a MNA concept.
I.1 Targets set by the authority for agreeing on framework conditions with obligated party	• The MNA concept is the result of checking an individual case. • The type and extent of the proof of the effectiveness of attenuation processes have to be concerted. • The basic requirement for remediation is not doubted by MNA. • MNA as sole measure is only possible if the site-related prerequisites will be fulfilled and remediation measures assessed as being inappropriate. • If a remediation as a sole measure will be appropriate MNA will be unsuitable. • A concerted monitoring shall be carried out to check the effectiveness of the attenuation processes. • An alternative option for action is to be scheduled.
I.2 Checking of the site-related prerequisites according to the present state of knowledge	• Site potential • Contaminant input and reaction spaces • Presentation of the hydrogeological model
IInd step	Proof of the effectiveness of attenuation processes and preparation of a MNA concept
II.1 Site investigations to prove the effectiveness of attenuation processes	• Spatial position and expansion of the contaminant plume • Investigations to determine the contaminant loads at balance levels • Investigations for identifying and quantifying the essential individual processes • Investigations on the basis of a deficit analysis to prepare the prediction
II.2 Prediction of the development of the contaminant plume	• Preparation of a numerical model (flow, transport and reaction processes) • Assesment of the long-term course and the of the process • Representation of prediction uncertainties by means of scenario considerations and sensitivity analysis • Identification of the key parameters
II.3 Evaluation and assessment of the results	• Concluding evaluation and assessment of all marginal conditions and results of investigations • Site-specific assessment of remediation measures (upon completion of the remediation investigation)
II.4 Preparation of a MNA concept and explanation of its suitability	• Preparation of a MNA concept with its respective components of regulation • Monetary representation of the measures • Explanation of the suitability of the MNA concept
IIIrd step	
Administrative decision on the suitability and implementation of MNA	• Criteria for the decision: - Are the site-related prerequisites acc. to Chap. 4 of the text part fulfilled and, if yes, to which extent? - Does the MNA concept ensure the required monitoring intensity and does it provide the possibility of a punctual intervention? - For which areas of the groundwater damage will a remediation be appropriate and will have thus to be carried out? - For which areas of the groundwater damage will a remediation be inappropriate solely before the back ground of attenuation processes and a MNA will be the appropriate measure instead of a remediation? • Agreement on a binding instrument of regulation
IVth step	
Carrying out of MNA	• Execution of monitoring on the basis of a monitoring plan • Checking of the prediction (variance comparison), if necessary, adaptation of the approach • After reaching the target concluding assessment of hazards

3.3.2. Instructions for checking prerequisites

The second annex of the position paper gives a methodology to check prerequisites for carrying out MNA. There are chapters relating to the contaminant source and to the contaminant plume. A flow chart was composed to show ways of decision making for assessment of on site-investigations. It is presented in Figure 4.

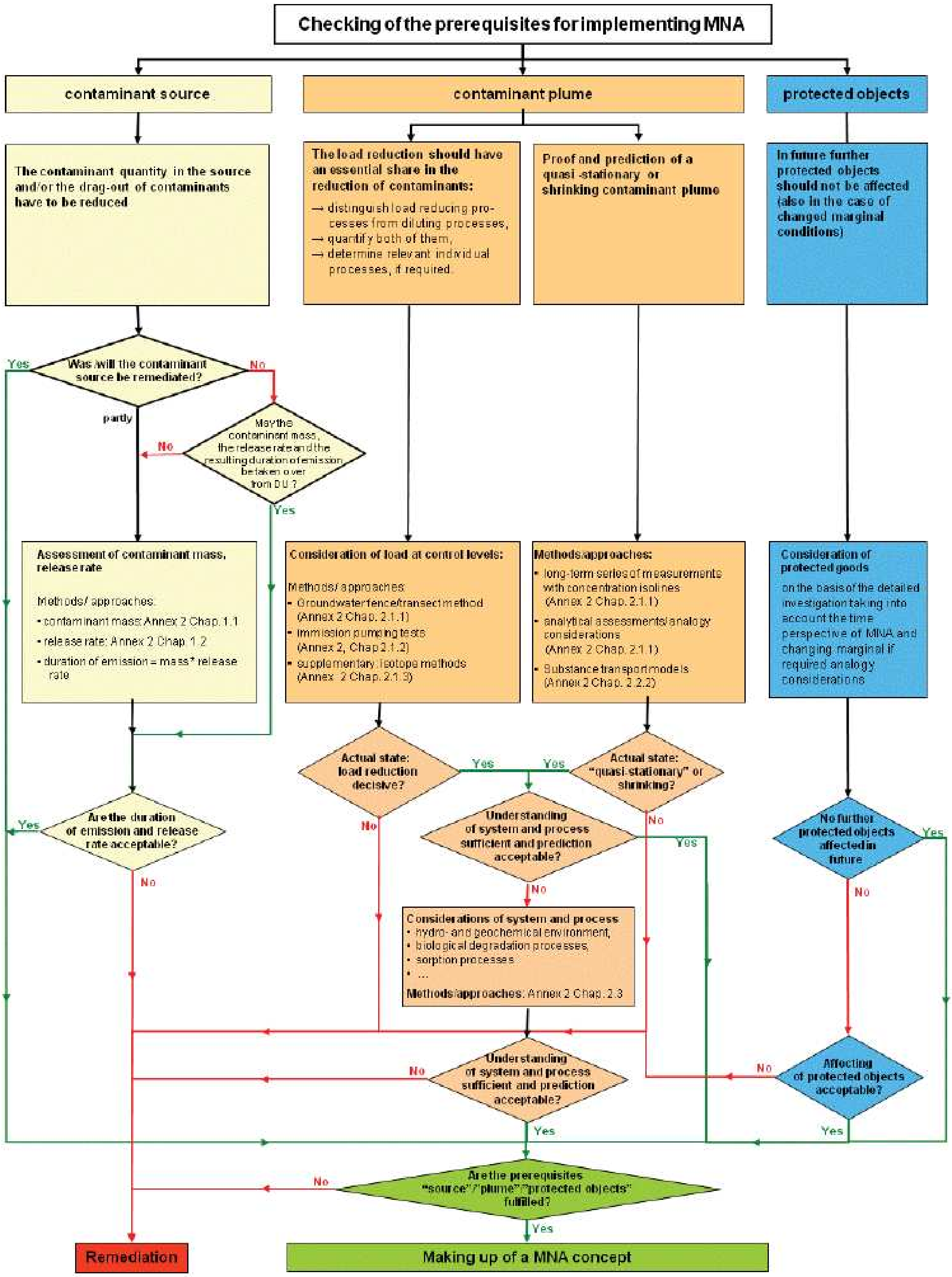

Figure 4. Flowchart: decision making for assessment of on site-investigations. (LABO, 2011, p.28)

3.3.3. Monitoring of the NA

The predicted effect of NA has to be proven and for this, monitoring is necessary. The position paper discusses a few requirements, listed below.

- What? Aspects relating to the contaminant source, the plume and processes of NA. Changes of hydro geological, geochemical, microbiological and other framework conditions have to be recorded. It is more than just the registration of contaminant concentrations!
- How long? At least until contaminant concentrations have reached the defined target values and it has been demonstrated that they will remain below those values permanently. LABO doesn't see fit to establish a maximum period.
- When? Specific times of monitoring in relation to intermediate targets.

(LABO, 2011)

3.4. HLUG guidebook for the application of MNA

The HLUG guidebook (volume 8, part 1) includes administrative measures for the use of MNA in the region of Hessen. However, MNA is only considered in the saturated zone (the non-saturated zone is not part of this guidebook). It offers guidance on the evaluation and implementation of MNA.

3.4.1. Can MNA be applied?

The guidebook mentions several criteria for the evaluation of whether or not MNA can be applied, e.g. the biodegradation ability; the generation of toxic compounds; transfer of the contamination to other aquifers; changes in groundwater levels; the contamination plume and concentrations, … A checklist which covers the most important criteria is presented in the guidebook.

3.4.2. Implementation of MNA

Also explained in the guidebook are the three basis steps to implement MNA:

1. Evaluation the NA-processes and assessment of the contamination development
2. Implementation of the long term monitoring program
3. The "concept of alternatives" should MNA prove to be ineffective

(HLUG, 2005)

3.5. Manual for the use of biological remediation techniques

This manual was published in 2006 by ICSS, it includes among other things a decision-making matrix for the use of MNA and other techniques. This matrix is shown in Table 6. The indication '+'; '0' and '-' stand respectively for: 'suitable'; 'suitable with restriction' and 'unsuitable'.

	ex-situ			in-situ methods								
				unsaturated						saturated soil		
	land farming	biobeds	reactors	in-situ land farming	bioventing	biosparging	hydraulic cycles	biosparging	GW circulation wells	bio-screens	funnel-and-gatre	**natural attenuation**
light non-aqueous phase liquid existing	-	-	-	-	-	+	-	0	+	-	-	-
dens non-aqueous phase liquid existing	-	-	-	-	-	+	-	-	+	-	-	-
mineral oil hydrocarbons	+	+	-	-	+	+	+	+	+	-	-	+
BTEX	-	0	-	-	+	+	+	+	+	+	+	+
PAHs (preferably low-condensated)	-	0	+	0	-	-	0	0	0	0	0	0
phenols	-	+	-	-	+	+	+	+	+	+	+	+

volatile chlorinated organic compounds	-	-	-	-	-	-	+	+	+	+	+	+
chloroaromatics	-	0	+	-	0	-	+	-	-	-	-	-
explosive-typical compounds	-	+	0	+	-	-	-	-	-	-	-	-
unsaturated soil is contaminated up to 2m in depth	+	+	0	+	0	-	-	-	-	-	-	-
unsaturated soil is contaminated deeper than 2m	+	+	-	-	+	0	-	-	-	-	-	-
saturated soil is contaminated	-	-	-	-	-	-	+	+	+	+	+	+
saturated soil is contaminated at great depth	-	-	-	-	-	-	0	0	-	0	-	0
complex mixture of hardly degradable pollutants	-	0	+	-	-	-	0	-	-	0	-	-
soil shows a low permeability	+	+	+	0	-	-	-	-	-	+	+	+
soil shows a high permeability	+	+	-	-	+	+	+	+	+	0	0	0
unsaturated soil is strongly heterogeneous	+	+	+	+	-	-	-	-	-	-	-	-
saturated soil is strongly heterogeneous	-	-	-	-	-	-	-	-	-	+	+	0
small place for remediation plants available	-	-	+	+	+	+	-	+	+	+	+	+
short remediation time required	-	-	+	-	-	-	+	+	-	-	-	-
combination with bioaugmentation possible	0	0	+	+	-	-	0	-	0	-	-	-
small financial funds available	+	-	-	+	+	-	-	-	-	+	+	+

Table 6. Decision-making matrix from ICSS. (ICSS, 2006, p.68)

3.6. Techniques

3.6.1. Evaluation of NA-processes

The LABO paper (2011) lists some methods to evaluate different NA processes:

(1) Biodegradation

- Indirect indications of biodegradation activity: routine measurement of parameters (e.g. redox potential, temperature, concentration of hydrogen carbonate);
- In situ methods for the measurement of biodegradation activity e.g. determining functional genes;
- Degradation rates to predict the degradation of contaminants:
  - Taken from literature;
  - Obtained in laboratories from microcosm studies;
  - Or determined by in situ methods e.g. sampling techniques, determination of isotope fractioning.
- Metabolites in the plume.

(2) Chemical transformation

- Investigation of conditions e.g. availability of reactants, oxidation-reduction conditions.

(3) Sorption

- Quantification through batch and column tests of material taken from the site and under similar conditions (pH, temperature, …);
- Sorption parameters can be taken from literature;
- Determination of the site-specific carbon content in the solid matrix;
- Check whether it is possible that desorption processes take place if site conditions (hydrochemical, geochemical) are altered.

(4) Hydrodynamic dispersion

- Assessment through e.g. tracer tests[6].

[6] « Conservative », non reactive tracers.

3.6.2. Evaluation of the contamination plume

In order to evaluate the plume and to predict its further behaviour, the position paper mentions:

- That it is necessary to know horizontal and vertical spreading of the plume;
- That it is required to predict temporal changes in order to evaluate the plume behaviour. Two aspects are important:
    - Simple analytical calculation methods can be used to perform a worst case assessment, in order to find out if the plume is stationary, if it recedes or expands further. This is important with regard to risks for groundwater and further protected objects (shifts to other aquifers e.g.);
    - The drag-out rate of contaminants in comparison with the attenuation rate in the plume determines whether the contaminant plume is "quasi-stationary" or diminishing.
- And that the prediction of plume behaviour should be based on a conceptual, hydrogeological site model[7].

3.6.3. Assessment of MNA

In annex II of the position paper, several methods are discussed with relation to the application of MNA. These methods are discussed extensively in the KORA guidebooks and recommendations, or in the LABO Working Aid on leachate prediction. The ones named in the position paper and listed hereafter are related to the contaminant source and the contaminant plume.

(1) Contaminant source

- Assessment of the contaminant mass.
    - Determination of the spatial expansion of the contaminants: soil or groundwater sampling during sounding/probing followed by laboratory analysis.
        - Direct push sounding (e.g. MIP, LIF);
        - Development of measuring points that allow a deep differentiated sampling of soil air and groundwater;
        - Measurements in soil air samples (e.g. measurement of radon in LNAPL situations);
        - Pumping tests to determine phase mobility.
    - Assessment of the contaminant mass.
        - Interpolating the contaminant contents and multiplying them with the respective volume;
        - Analytical calculation of the contaminant mass through spatial integration of saturation profiles.
    - Determination of extensiveness of sorption to the soil matrix.
- Assessment of the release rate[8] of contaminants
    - Prediction instrument ALTEX-1D (developed by LABO): puts into practice information gathered from column experiments and chemical-physical data;
    - Determination of the actual release rate: load consideration.

[7] Further specifications for software use and targets for application of a mathematical model are not set in the position paper.
[8] The release rate is calculated by multiplying the source strength (contaminant mass coming from the source per time and are unit; mass flow density) with the area size of the source.

(2) Contaminant plume (when information about the spatial concentrations of the contaminants is available[9])

- Load consideration at control levels
  - Groundwater fence/transect approach (dense raster of measuring points, e.g. direct push sounding; if desired accompanied by passive collector units);
  - Immission pumping test: pumping measures at appropriate wells and determination of concentration curves;
  - Isotope methods to clarify whether detected load reductions or concentration recessions are due to biodegradation: determination of isotope signatures (at control levels) and quantification of biodegradation using process-specific fractionation factors determined in the laboratory.
- Proof and prediction that the plume is "quasi-stationary"
  - Series of groundwater measurement
    - During many years; at sufficient number; correctly positioned in the plume and its environment to develop concentration curves and isolines;
    - When there are no time series available: calculations of analytical models based on simplified site conditions.
  - Substance transport models (for complex situations). These models are based on conceptual site models.
    - Including hydrogeological and hydrochemical conditions;
    - Based on detected degradation and sorption processes;
    - Including sensitivity analysis and scenario considerations.
- Assessment of NA processes
  - Determination of hydrochemical and geochemical media
    - Oxidation-reduction and other physical-chemical parameters;
    - Present and future availability of electron acceptors and donors;
    - When desired a supplementary method to determine redox bands;
    - Accompanying contaminants that influence the degradation and transformation processes;
    - Marginal hydrogeological conditions such as fluctuations of groundwater levels.
  - Biodegradation processes
    - Isotope methods;
    - Microbiological methods: bacterial counts (growth and findings on substance degradation); degradation experiments and microcosm studies; investigations of microbiological activity and detection of specific mechanisms (PCR detection of genes, in-situ fluorescence probes, …).
  - Sorption processes
    - Transfer from literature of sorption data;

[9] If not, similar methods as the ones used for exploration of the contaminant source can be applied.

- Determination of site-specific sorption isotherms.

- Volatilization processes
    - Simplifying analytical model calculations (Fick’s law);
    - Numerical transport models
- Contaminant specific methods
    - Gas chromatography for determination of mineral hydrocarbons and BTEX;
    - Measurement of isotope signature changes for BTEX degradation;
    - Detection of declining electron acceptor levels for mineral hydrocarbons and BTEX degradation;
    - Microcosm studies for mineral hydrocarbons and BTEX;
    - Prove of microbiological potential through the MPN method for mineral hydrocarbons and BTEX;
    - Loads of mineral hydrocarbons and BTEX;
    - Substance loads for mineral hydrocarbons and BTEX as a result of consumption of redox equivaltents;
    - Physical-chemical properties (e.g. boiling point, water solubility) are relevant for assessing NA of MTBE;
    - Detection of TBA in groundwater as an indication for aerobic degradation of MTBE;
    - Determination of cell populations in soil and aquifers (MPN methods/determination of number of nuclei) for MTBE;
    - In-situ fluorescence probes for MTBE;
    - Quantifying specific metabolites of MTBE degradation;
    - Hydrochemical and hydrogeochemical investigations for PAH;
    - Semi-quantitative assessment by determining the decline of electron acceptors as a indication of degradation of PAH (and comparison with decrease of PAH compounds);
    - Specific bacterial counts (MPN) in the aquifer for PAH;
    - Determination of the biodegradation share by isotope methods for PAH (however, this method is up till now limited to naphthalene);
    - Determination of sorption (KOC values and carbon content of the soil) for PAH;
    - Assessment of spreading of individual contaminants withoud degradation (analytical calculation models) for PAH;
    - Guiding parameters for PAH such as BTEX and electron acceptors;
    - Determination of starting substances and their metabolites for HVCHC;
    - Control of the occurrence of specific degradation organisms for HVCHC (such as *Dehalococcoides sp*.), sometimes by means of isotope methods;
    - Quantification of retention processes for HVCHC;

- Qualitative detection of degradation for HVCHC through isotope methods or molecular biological investigations (detection of *Dehalococcoides sp*.);
- Microcosm studies for the identification of degradation processes of HVCHC;
- Quantification of degradation processes of HVCHC such as isotope methods and stoichiometric conditions of substances and their metabolites;
- Determination of all substances, metabolites, relevant parameters and electron acceptors for HVCHC.

- Considerations for further protected objects

(LABO, 2011)

4. Lessons from the application of NA

The ICSS publication from 2006 mentions a few prerequisites for the application of MNA; advantages and disadvantages of the approach. Obstacles for implementation were found in a presentation by Rüttinger and in the ITVA guidance document.

- *Prerequisites for the application of MNA*

If MNA is an option for remediation; it has to be determined that the microbial degradation of contaminants is the dominating process for their removal, otherwise, MNA should not be implemented. A site-specific hazard assessment should be performed, to make sure that sensitive objects of protection are not affected by the contaminants in the plume. Furthermore, MNA should lead to the reaching of site-specific remediation objectives and the development of the plume should be reliable in time and space. (ICSS, 2006)

- *Advantages and disadvantages of MNA*

The mentioned advantages are the low cost and that there is no need for intervention in the subsoil. Disadvantages on the other hand are the costs due to the long time period that is needed for remediation (monitoring) and the fact that the aquifer cannot be used for a long time. (ICSS, 2006)

- *Obstacles*

From the "Working with nature" presentation by Rüttinger (2010), it shows that application of MNA in Bayern is limited. The presentation mentions several reasons for this;

- the duration of the MNA projects is too long;
- the complexity of the cases and the practical remediation complicates decision making;
- numerical models and necessary investigation measures come at high costs;
- there is uncertainty about whether or not the remediation goals will be fulfilled, which means that the back-up plan must include alternatives of active remediation.

Other possible obstacles for acceptance (ITVA, 2004) are:

- equivocal definitions of NA, MNA and ENA;
- MNA is considered in different ways: as a process, as an investigation measure, as a remediation measure and as protection or restriction measure;
- uncertainties about implementation.

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). As Table 4 (paragraph 1.2.3) shows, 27 remediation projects were found online where MNA was applied for a limited number of region states. We know that this number is an underestimation of the total amount of MNA cases in Germany; as presented on the SNOWMAN workshop on MNA in Paris: over a 100 MNA cases exist. Even more importantly, although we know the existence of these projects, the return on experience (e.g. success/failure reasons; costs; duration; obstacles during implementation; performance) is even more limited.

From the MNA-projects in Baden-Württemberg, we can learn that MNA in that region is mostly applied as a stand alone technique, without additional other measures for remediation (twelve out of thirteen projects). With regard to the project advancements we can learn that, in 2010, MNA has been legally approved for seven out of thirteen projects. MNA is already being applied at four sites.

From the information on MNA remediation in Bayern we can learn that so far, MNA has only been considered in combination with active remediation measures in this region (all seven projects up to 2010). Furthermore, with regard to the project advancements: four out of seven are in the planning phase and only one site has started the actual monitoring of NA.

The case in Berlin also combines MNA with active remediation of the site: MNA is being applied to manage the residual contaminant concentrations.

From the information found for Hessen; we can learn that the application of MNA has increased in the last few years. The information available for the Kassel site teaches us that in general: (a) patience is required when applying MNA, since NA-processes can be very slow and (b) this requirement for patience can result in difficulties to get approval for MNA projects.

Furthermore, an additional example was found online for the former military airfield Wegberg-Wildenrath. Here as well, MNA is applied in combination with active measures.

In summary we know that:

- over a 100 MNA cases exist in Germany;
- the application of MNA in Germany is increasing;
- the application of MNA in Germany varies between the different Länder;
- remediation projects in Germany use MNA as a stand alone technique as well as in combination with other measures;
- patience is required when applying MNA and this can cause problems with administration and approval of the remediation project!

6. Timeline

Figure 5 shows the timeline for Germany including research projects and guidelines, protocols and methodologies concerning NA. The first case of MNA application (that was found online) started 1996.

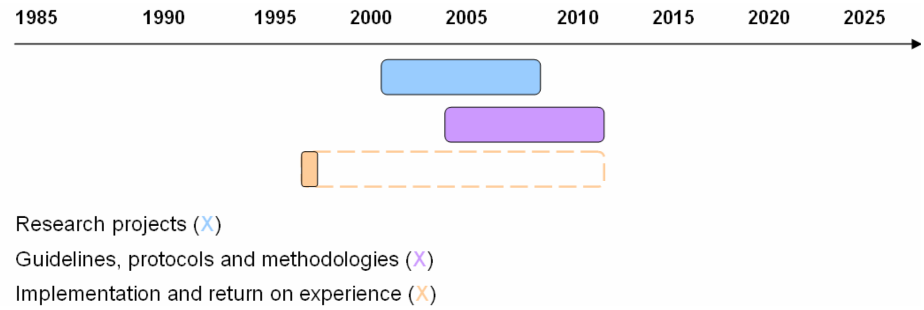

Figure 5. Timeline for Germany.

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8. List of abbreviations

AÜP	Überwachungsprogramms für Altablagerungen in der Stadtgemeinde Bremen
BBodSchG	Bundes-Bodenschutzgesetz; Federal Soil Protection Act
BBodSchV	Bundes-Bodenschutz- und Altlastenverordnung; Soil Conservation and Contaminated Site Ordinance
BMBF	Bundesministerium für Bildung und Forschung
BTEX	benzene, toluene, ethylbenzene and xylene (volatile organic compounds)
GAB	Gesellschaft zur Altlastensanierung in Bayern mbH
HLUG	Hessiches Landesamt für Umwelt und Geologie
HVCHC	highly volatile chlorinated hydrocarbons
ITVA	Ingenieurtechnischer Verband Altlasten e.V.
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)
LABO	Bund/Länder-Arbeitsgemeinschaft Bodenschutz ; Federal State Working Group on Soil Protection
LIF	laser induced fluorescence probes
LNAPL	light non aqueous phase liquid
MIP	membrane interface probe
(M)NA	(monitored) natural attenuation
MTBE	methyl tertiary butyl ether
PAH	poly(cyclic) aromatic hydrocarbons
RETZINA	Reference Test Site Zeitz for the Implementation of the Natural Attenuation approach
UBA	UmweltBundesAmt