SNOWMAN NETWORK
Knowledge for sustainable soils

State of the art concerning MNA in Europe – Sweden

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Enhanced and Monitored Natural attenuation of chlorinated aliphates - experience and status in Sweden

This document aims to briefly describe experiences in Sweden concerning monitored natural attenuation (MNA) and enhanced attenuation (EA). The status document mainly focuses on chlorinated aliphatic hydrocarbons (CAH), and petroleum hydrocarbons are only briefly discussed.

In the document, enhanced attenuation of CAH is considered an in situ remediation method where natural attenuation is stimulated, or supported by using additives. Air sparging, reactive barriers etcetera are not included in the document.

1. Summary of Sweden's experience of MNA and EA

1.1. Petroleum hydrocarbons

The concept of MNA and EA for petroleum hydrocarbons has been recognized as a remediation strategy for more than 15 years in Sweden. It is, however, not a commonly used remediation method. For example, in only one case among 1400 remediated closed-down petrol stations, MNA was the chosen remediation technique. According to SPIMFAB, the fund responsible for managing, investigating and remediating closed-down and contaminated stations, stakeholders generally tend to prioritize the shorter remediation times offered by other techniques such as dig and dump, air-sparging or bioventing. Furthermore, the remediation fund as such, used by SPIMFAB for these remediations have somewhat had time limited usage. The organisation SPIMFAB was formed in 1996.

The Geological Survey of Sweden (in Swedish, SGU) is currently monitoring 30 underground oil storages where natural attenuation is on-going (although these are not officially defined as MNA-projects). The Geological Survey is the responsible party for managing and cleaning-up of former hard rock underground oil storages in Sweden. Until today, they have been investigating and monitoring civil underground storages for more than 10 years. NA-processes in hard rock storages (foremost aerobic microbial degradation) have been recognized within a scientific programme with the aim of characterizing oil degradation in hard rock storages in general, i.e. each former oil storage has not been exposed to a site specific MNA-investigation. Within the programme, degradation products have been identified and bacterial growth has visually been noticed during aeration of the storages, and hence microbial degradation is considered on-going. A simplified monitoring programme is running for each of the storages and is being revised every 5 year. Due to the specific environment the underground storages present, SGU have not been able to quantify degradation rates and to make detailed prognoses on time needed until acceptable contamination levels will be reached. Their calculated monitoring time is, however, until the year 2050, meaning 50 years of surveillance including time past until now. No goals have been determined, but will most likely be close to drinking water standards.

An official guideline report on NA-investigations, "Natural Attenuation of sites contaminated by petroleum hydrocarbons - a guideline", was published in 2004 (SGI, 2004). A full scale MNA remediation project at a contaminated former petrol station has been performed in connection with the guideline project (SGI, 2004b).

1.2. Chlorinated hydrocarbons

MNA, as well as enhanced attenuation (EA), of chlorinated aliphatic hydrocarbons have so far been sparsely used in Sweden. One of the reasons may be the path that Sweden has chosen to finance remediation of contaminated land, meaning that from the 1990's and until now, most remedial activities have been funded by the State and associated with demands on quick realizations and a quick accomplishment – two conditions not compatible with either MNA, or EA. Other reasons may be

that Sweden traditionally has focused on soil and remediation of soil (less than 50% of the groundwater is used for drinking water purposes); or the absence of technical guidance documents and a lack of full scale knowledge/experiences within biogeochemistry, microbiology or environmental chemistry.

In 2006, a national inventory of full scale remediation projects in Sweden between the years 1994 and 2005 was published. The inventory contained detailed information on 226 remediated sites. Among the 226 sites, only one, *the Fröslundatvätten* in the city of Eskilstuna, involved some kind of stimulation of natural attenuation processes, i.e. injection with bacteria (Hållbar sanering, 2006).

However, the chemical and biological processes and the possibility to reduce unsaturated CAH's to VC and further to ethene and ethane have for long been theoretically established and considered a promising method with a high potential of success. In 1998, the Swedish EPA in collaboration with the *Miljöteknikdelegationen* (a delegation for promoting environmental techniques), invited land owners, environmental consultants and treatment companies and facilities to participate in a technical demonstration project regarding the treatment of CAH contaminated soil and groundwater. A former tannery, f.d. Glacé-läderfabriken in Kävlinge, was chosen as one of several pilot projects and involved on site, biological anaerobic reduction of TCA and TCE in groundwater. Laboratory tests performed between 1995 and 1996 showed that biological dechlorination of the contaminated groundwater in Kävlinge could be stimulated by adding either acetate or methanol and allowing natural processes to continue its work. In 1999-2000, the pilot project focused on pumping groundwater through different treatment reactors, and reintroducing this groundwater back into the ground, resulting in a decrease in concentrations of CAH's as well as obtaining a well-functioning microbial population. The project was ended in 2000.

Further national activities regarding the development of remediation techniques were carried out in Stockholm 1998-1999 (the demonstration project *Lyftkranen*). However, with a limited time period available for treatment (less than a year) *in situ* MNA and EA were considered unsuitable for the project.

The general use and awareness in Sweden of MNA and EA has followed a general trend, with a gradually increasing awareness of the methods and a successively increasing level of knowledge, starting by technology transfer between national and foreign environmental consultants. Apart from the United States, Canada and the Netherlands, Denmark has played an important role in inspiring Swedish consultants and governmental representatives by arranging technology transfer meetings and by sharing their knowledge through comprehensive documentation.

As regulators and consultants successively gained knowledge and the branch matured, more and more attempts have been made to carry out investigations, pilot tests and perform full scale treatment by MNA/EA. Since 2006 several reports and technical guidance documents regarding MNA and EA have been published, e.g.:

Natural attenuation of chlorinated hydrocarbons – a guideline

- *Naturlig självrening av klorerade alifater – vägledning*, Swedish Geotechnical Institute (SGI), Varia 601 (SGI, 2009

Monitored Natural Attenuation as a remediation strategy on contaminated sites

- *Övervakad Naturlig Självrening som åtgärdsstrategi på förorenade områden*, Hållbar sanering Rapport 5893, 2009

Remediation goals for in-situ treatment; Formulating remediation goals and monitoring.

- *Åtgärdsmål vid in-situsanering, Formulering och kontroll av åtgärdsmål*, Swedish Geotechnical Society (SGF) Rapport 2, 2009

Chlorinated hydrocarbons – Characterisation of CAHs and how to choose remediation technique

- *Klorerade lösningsmedel - Identifiering och val av efterbehandlingsmetod*, Hållbar sanering Rapport 5663, 2007

The Swedish Geotechnical Institute has chosen to define MNA according to the definition made by US EPA (1999) in the SGI MNA guideline for chlorinated aliphates. The guideline document is not legally binding, i.e. it offers guidance. However, several local environmental authorities have put the guideline into practice, and there is a kind of general acceptance for the approach. Following the definition, main processes included in MNA are:

- Microbial degradation
- Abiotic, physical-chemical, degradation
- Precipitation
- Sorption
- Advection, dispersion and diffusion
- Vaporization

Seminars and workshops have been held with the aim of raising awareness and render acceptance for the methods and expected results. Meetings have been arranged by the Swedish network on contaminated land (in Swedish *Nätverket Renare Mark*), the Swedish Geotechnical Society (in Swedish SGF) and different educational societies (e.g. *Marksaneringscentrum Norr* in collaboration with *Umeå Technical University*, *Chalmers University of Technology* etc.) as well as environmental consultants. Additional technical reports, focusing on EA, are currently being prepared by the Swedish geotechnical society (in review) and the Swedish Geotechnical Institute (on-going).

It appears that enhanced attenuation is more attractive compared to just monitoring the situation as an MNA project. Presently some MNA-projects are transforming into EN-projects, although they are not yet in full scale performance. If the change is due to poorly understood processes, general miscalculations in the prognosis, or is just a symptom of the eagerness to learn more of the EA-processes, is uncertain. The use of especially enhanced attenuation has just started to become accepted in Sweden, and today many advisors and consultants search every possibility to adopt the technique.

Compared to other remediation techniques such as thermal heating or resistivity heating, MNA and EA are cheap and cost effective alternatives. However, the preceding investigation phase can be time consuming and is also rather expensive. For the development of MNA and EA in Sweden, it is initially important to support and finance well planned projects with a high potential of success, and not to avoid costs for investigation, preparation and planning. Evaluations of successful and unsuccessful, full-scale projects need to be published and made available to interested stakeholders. The successful development of the technique will be dependent on these full-scale projects and consequently, Sweden needs to realise more pilot- and full-scale performances. In order to do this, the information about MNA and especially EA needs to be increased, not least to the authorities and other stakeholders.

2. Projects/case studies carried out

MNA/EA projects carried out in Sweden are listed in Table 1. Information on the projects were collected by a brief survey, initiated by the SNOWMAN project and conducted by contacting key regional environmental authorities, consulting companies and entrepreneurs. The list is not complete but it is estimated to contain about 75% of the total.

As given in Table 1, five EA and two MNA full scale projects have been carried out or are ongoing in Sweden. Furthermore, a project using active coal and iron are also mentioned. This project is a mixture between using chemical oxidation and enhanced natural attenuation but it's an interesting project to mention. The overall risk reduction aim is to protect drinking water and in a few cases the indoor climate as well.

An example of the use of EA in Sweden is the project "*Söderkaj"* in the city of Halmstad, southeast of Sweden. Söderkaj was a full scale project that used stimulated natural attenuation as a remediation method. The full scale project had a successful outcome which has been important for gaining acceptance for the technique by stakeholders and authorities. In Söderkaj the groundwater was contaminated with *cis*-1,2 dichloroethene (DCE) and vinylchloride (VC) (HSB, 2009). The carbon source used was 3-D Microemulsion (3DMe®) from Regenesis LTD (Davidson and Leonard, 2010). Two injection periods were conducted with one year apart (June 2008 and June 2009) in injection points placed about 4-5 m apart. Groundwater samples were taken before and after the injections and the analytical results showed degrading concentrations of DCE and VC after the injections. In November 2009 only 3 of 11 groundwater wells had concentrations above the remediation goal (100 µg/l of total CAH).

3. References

L. Davidsson, 2010. Söderkaj – Halmstad. Klorerade lösningsmedel. Undersökningar och åtgärder.

http://www.wspgroup.se/upload/documents/Sweden/6%20Lars%20Davidsson.pdf

L. Davidsson, Leonard G., 2010. Treatment of Chlorinated Solvents using 3-D Microemulsion (3DMe®) allows for Housing Redevelopment in Sweden.

http://www.slideshare.net/gleonard35/3-d-me-wsp-sweden-sderkaj-halmstad

Hållbar sanering. J Helldén, B Juvonen, T Liljedahl, S Broms, U Wiklund, 2006. Åtgärdslösningar – erfarenheter och tillgängliga metoder. Hållbar sanering. Rapport 5637

http://www.naturvardsverket.se/Documents/publikationer/620-5637-9.pdf

Hållbar sanering. P Englöv, E Cox, N Durant, J Dall-Jepsen, T Hojbjerj Jorgensen, J Nilsen, N Törneman, 2007. Klorerade lösningsmedel - Identifiering och val av efterbehandlingsmetod. Rapport 5663

http://www.naturvardsverket.se/Documents/publikationer/620-5663-8Del1.pdf

Hållbar sanering. N Törneman, L Karlsson, P Englöv, E Cox, N Durant, C Azziz, J Dall-Jepsen, 2009. Övervakad Naturlig Självrening som åtgärdsstrategi på förorenade områden. Rapport 5893.

http://www.naturvardsverket.se/Documents/publikationer/978-91-620-5893-7.pdf

HSB, 2009. Söderkaj, Halmstad. Redovisning av utförda avhjälpandeåtgärder (in situ sanering) på Söderkaj, 2009-12-01

http://www.ejlskov.com/assets/files/Dansk/Cases/Soderkaj.pdf

SGI (Swedish Geotechnical Institute). L Larsson, 2009. Naturlig självrening av klorerade alifater – vägledning. Varia 601.

http://www.swedgeo.se/upload/publikationer/Varia/pdf/SGI-V601.pdf

SGI (Swedish Geotechnical Institute). L Larsson, B Lind, 2004. Naturlig självrening av petroleumförorenade markområden– Vägledning. Varia 541-1.

http://www.swedgeo.se/upload/publikationer/Varia/pdf/SGI-V541-1.pdf

SGI (Swedish Geotechnical Institute). L. Larsson, B. Lind, A. Gabrielsson, 2004b. Naturlig självrening av oljeprodukter i mark och grundvatten – Pilotstudie i Brånshult, Östergötland. Varia 541-3.

http://www.swedgeo.se/upload/publikationer/Varia/pdf/SGI-V541-3.pdf

SGF (Swedish Geotechnical Society), 2009. Åtgärdsmål vid in-situsanering, Formulering och kontroll av åtgärdsmål. SGF Rapport 2:2009.

http://www.sgf.net/web/page.aspx?refid=31

US EPA, 1999c. Monitored natural attenuation of chlorinated solvents. U.S. EPA Remedial Technology Fact Sheet. EPA/600/F-98/022.
http://www.epa.gov/ada/download/fact/chl-solv.pdf

Table 1 Status - Experiences with natural / enhanced attenuation of chlorinated solvents – Sweden SNOWMAN (A3 format)

Method	Phases conducted - Investigation (I), Pilot (P), Full scale (F)	Used additive(-s)	Contaminant (initial)	Treatment volume (app. m3)	Mitigation objective (Risk reduction) * note below	Max. Concentrations	Free product phase (DNAPL)	Geology	Site location	Executer	Financier	Responsible authority	Project_period - expected	Remediation goal	Ref. Documents (pdf or link)	Info from
Monitored Natural Attenuation	I, P, F (implemented and ongoing)	-	Chlorinated solvents (TCE –VC)	-	IC	2 800 µg/l (TCE) 380 µg/l (VC)	No	Silty peat / silty sand / silt	S Sweden, former manufacturing plant	URS Nordic AB	Private Operator	Municipality	2000-2012	Gw. conc. Already below SSGV. Confirm occurrence of ongoing natural attenuation processes.	Not available	URS Nordic AB
Monitored Natural Attenuation	I, F	-	Chlorinated solvents (PCE -> VC)	10.000 m3	GW/IC	8 000 µg/L	Possibly residual	Silt/till overlayed by clay	County of Örebro, former drycleaner	Golder Associates AB	Private Operator	Municipality of Örebro	1997-2017	No goal	Not available	Golder Associates AB and HIFAB
Monitored Natural Attenuation	I	-	Chlorinated solvents (PCE -> VC)	3-5.000 m3	GW	12 000 µg/L	Possibly residual	Till and bedrock overlayed by clay	County of Västmanland, former drycleaner, Västerås	Golder Associates AB	Private Operator	Municipality of Västerås	2000-	Not yet decided	Not available	Golder Associates AB
Monitored Natural Attenuation	I	-	Chlorinated solvents (PCE -> VC)	20 000 m^3	GW, county drinking water supply	50 000 µg/L	Possibly residual	Till/ sandstone	Färgaren 3, former drycleaner	Hifab AB	SEPA via the municipality of Kristianstad	Municipality of Kristianstad	2009-2011	GW: <100 µg/l of total CAH	Numerous documents available through the municipality of Kristianstad	HIFAB
Monitored Natural attenuation	I	-	Chlorinated solvents (1,1,1-TCA, TCE)	?	R	TCA 1 300 mg/l, TCE 190 mg/l	Yes	Clay till, sedimentary bedrocks	Kävlinge, County of Skåne	Sweco Environment	Swedish EPA	County Adm, Skåne	1995-1996	No goal	Certain documentation available through the county adm.	Sweco Environment
Monitored Natural attenuation	I	-	Chlorinated Solvents (PCE -> VC)	3-5.000 m3	GW	PCE: 8000 µg/l TCE: 2800 µg/l	No	Layered area with clay/sand	Alingsås	SGI	Private Operator and SGU	Municipality of Alingsås	2006-2009	No goal. Prognosis based on MNA indicated need for active remediation. Investigation undergoing on the suitability for ENA	-	SGI
Enhanced Attenuation	I,P (benchscale tests)	Molasse and lactate tested HRC and 3DM (Regenesis) suggested	Chlorinated solvents (PCE -> VC)	2 000 m3	GW, county drinking water supply	18 000 µg/L	Residual	Silt/sand/ clay (sand/gravel below the treatment zone)	County of Jönköping, former drycleaner "Värnamo-tvätten"	Project management: Hifab AB. Design: Golder Associates AB. Performer: RGS 90	Swedish EPA via the municipality of Värnamo	County Adm, Värnamo	2011-2017	GW: <10 µg/L of total CAH (the design was done based on the original goal of <32 µg/L of PCE-eqv.)	Numerous documents available through Värnamo County	Golder Associates AB and HIFAB
Enhanced Attenuation	I, P, F	Sodium lactate, small hotspot, in gw	Chlorinated solvents (PCE -> VC)	100 m^3	GW	8 000 µg/l PCE	No	Clayey till	County of Skåne, SW Sweden	Golder Associates AB	Private Operator	Municipality of Helsingborg	June 2011-june 2012	1 800 µg/L PCE	Certain documentation available through the municipality	Golder Associates AB
Enhanced Attenuation	I, P, F	Sodium lactate	Chloroform CM -> DCM	75 m^3	GW	1 300 µg/L chloroform 1 400 µg/L methylene dichloride	No	Dry clay and Clay	County of Uppsala	Golder Associates AB	Private Operator	Municipality of Uppsala	june 2011-dec 2012	Dutch intervention values gw, 1000 ug/L chloroform, 400 ug/lL methylene dichloride	Certain documentation available through the municipality	Golder Associates AB
Enhanced Attenuation	P	Lactate acid and acetate	Chlorinated Solvents ?	300 m3	R	1000 µg/L	No	Silt/sand	Gnosjö, County of Jönköping	RGS 90	Private Operator	County Adm, Jönköping	2007-2008	Not decided Circulation method for additative worked unsatisfactory	Not available	RGS 90

Table notes: * Risks: GW = groundwater, IC = indoor climate, R = recipient, PC = physical contact/soil handling

Method	Phases conducted - Investigation (I), Pilot (P), Full scale (F)	Used additive(-s)	Contaminant (initial)	Treatment volume (app. m3)	Mitigation objective (Risk reduction) * note below	Max. Concentrations	Free product phase (DNAPL)	Geology	Site location	Executer	Financier	Responsible authority	Project_ period - expected	Remediation goal	Ref. Documents (pdf or link)	Info from
Enhanced Attenuation	I, F	3DMe (Regenesis)	Chlorinated Solvents (TCE -> VC)	4 500 m3	GW, IC	7 000 µg/l	No	Silt/Clay	Rampen 36, Falkenberg, County of Halland	WSP / RGS 90	Private Operator	Municipality of Falkenberg	2010-	GW: PCE = 100 µg/l, TCE = 80 µg/l, cDCE = 300 µg/l, VC = 25 µg/l	Numerous documents available through the municipality of Falkenberg	WSP / RGS 90
Enhanced Attenuation	I, F	3DMe (Regenesis)	Chlorinated Solvents (cDCE -> VC)	3 500 m3	GW, IC	25000 µg/L	No	Silt/Clay	Bojen 1, Söderkaj, Halmstad, county of Halland	WSP/ Ejlskov	Private Operator	Municipality of Halmstad	2008-2011	GW: 100µg/l of total CAH	Presentation available: http://www.wspgroup.se/upload/documents/Sweden/6%20Lars%20Davidsson.pdf Also: http://www.ejlskov.com/assets/files/Dansk/Cases/Soderkaj.pdf	WSP / Ejlskov
Enhanced Attenuation	I, P	Soybean oil (Newman zone), bacteria culture (KB-1)	Chlorinated solvents (TCE —VC)	10.000 m3 (source area)	GW	TCE 80 mg/l	Possibly residual	Silt/sand	County of Jönköping	Sweco Environment	Private Operator	County Adm, Jönköping	2006-	Mass reduction, not yet decided	Certain documentation available through the county adm.	Sweco Environment
Enhanced Attenuation	I, F	EHC (Adventus)	Chlorinated Solvents (TCE -> VC)	2000 m3	GW, IC	6000 µg/L	No	Silt/Clay	Bryggan 1, Söderkaj, Halmstad, county of Halland	WSP/ Ejlskov	Private Operator	Municipality of Halmstad	2011 -	GW: 100µg/l of total CAH	Some documents will soon be available through the municipality of Halmstad	WSP
Trap and Treat	I, F	RPI Remediation products Inc. Trap and Treat Bos100	Chlorinated Solvents (PCE/TCE -> VC)	7 500 m^3 (source area + plume area)	IC	PCE 180 mg/L TCE 150 mg/L VC 5,1 mg/L	Yes	Clay-Moraine	Stockholm	ÅF/Ejlskov	Private Operator		2011	Soil gas: PCE 45, TCE 10, VC 0,5 mg/m^3. GW: PCE 11, TCE 3,6, VC 0,02 mg/L Soil: PCE 11-30, TCE 1,8-9 mg/kg TS		ÅF

Table notes: * Risks: GW = groundwater, IC = indoor climate, R = recipient, PC = physical contact/soil handling