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Cost-effective measures to control and contain groundwater contamination

title: The natural attenuation concept, a cost-effective measure to control and contain groundwater contamination

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ABSTRACT

The "NA-Screening" is a tool to distinguish between those contaminated sites, were Natural Attenuation (NA) is sufficiently effective to contain and minimize the groundwater contamination, and those sites, were it can't be used because of neighboring sensitive environment or insufficient NA effectiveness. The "NA-Screening" has a hierarchical structure with three steps. During the first step (A) site-specific data is acquired and collected and the surrounding is checked for sensitive protective goods. During the second step (B), which will be discussed a bit more detailed in this paper, the effectiveness of the retention and degradation processes (NA) is investigated and the possible endangerment of protective goods is checked. Only when the first two steps have a positive result the third step (C), the monitored natural attenuation (MNA) can commence. Even as these investigative tools are cheap, the method is scientifically sound and a cost effective-measure to control and contain groundwater contamination.

INSTANCE OF THE RESEARCH

In Germany more than 300.000 contaminated sites (LABO 2009) are registered. Most of them are to some extend investigated but only the most prominent polluted sites (23.500) were until now remediated with "technical" methods. Many are left as they are, such already indirectly using NA. To provide a scientific base for NA the Federal Ministry for Education and Research (BMBF) funding priority KORA (Acronym for the German — Kontrollierter Rückhalt und Abbau) (Michels et al. 2005) was brought into action. During this research program, natural attenuation processes in groundwater affected by of contaminated sites in Germany were identified, characterized and quantified. The aim of this research was to explore the extent to which natural attenuation (NA) can be used for remedial purposes of groundwater contamination and to generalize the results for a guideline, the "NA-Screening". As active remediation measures are for most of the groundwater contaminations too expensive, this concept provides a basis for planning, granting permission by public authorities and remediation measures for acceptable costs for the public. It has a hierarchical structure and was successfully evaluated in Germany under the guidance of the German environmental agency (UBA).

THE THREE STEPS OF THE "NA-SCREENING" CONCEPT

During **step A** an extended investigation about and around the site is conducted, to sample information about the size, the content, the age and the geological siting. Secondly the emissions into the groundwater should be thoroughly explored using the "groundwater screening" (Kühn 2009) and the distribution of the pollution downstream should be known. Furthermore data about the hydrogeological situation, the use of the surrounding area and the sensitive protective goods (e.g. potable water production wells, deep founded constructions) in the area should be collected. The aim of part A is to install a data basis on that could be decided whether the damage of the groundwater could be improved, as well as a damage or danger for sensitive protective goods downstream of the site has to be excluded.

Step B has the aim to prove, that NA is effective enough to contain the contamination in the already damaged groundwater area. The polluted groundwater should not progress; NA should achieve a steady state or reduction of the emission. To prove this effectiveness three lines of evidence were developed.

In **part B1** (Kühn et al. 2009) the reduction of the emission along a centre-line is measured geochemically and the results are summarized by the main ions, the trace elements, DOC and the AOX (tab.1). These parameters are compared to the regional baseline values and the evidence of retention is positive, when the baseline values are approached within an appropriate distance. Table 1 illustrates the variation of the contamination over time (for example from 1983 to 2003) and decrease in space, from very high values (violet) close to the source to near baseline values (green) in 250 m distance.

The appropriate distance depends on multiple factors as groundwater velocity and the distance to the next sensitive protective good. As the depletion should not only be achieved by dilution, it is necessary to use a method to prove that NA is as well achieved by mineralisation and metabolisation.

Table 1. Reduction of emissions as global prove for NA effectiveness.

Geochemical parameter	Year of sampling	Monitoring well downstream of the contaminated site			
		50 m	100 m	150 m	250 m
Σ main ion	1983				
	2003				
Σ trace elements	1983				
	2003				
DOC	1983				
	2003				
AOX	1983				
	2003				

Color	Colour	Collor	Colour
Very high	high	increased	baseline

The Theta-method (Θt/Θ) (Holzbecher et al., 2010) is used in **part B2** as a second check for effects of NA in the groundwater emissions. This method is based on the comparison of concentrations for a tracer and the attenuation substance.

Examinations of the mathematical analytical solutions show that the ratio of normalised concentrations θt/θ is expected to increase in space and time in the presence of NA, but to remain constant in case of dilution and diffusion only or of no degradation. Figure 1 is a screenshot of the Theta-software developed for the "NA-Screening". This facilitates the calculation of the tracer versus the attenuation component and the results are displayed at the window at the right bottom. The increase of the ratio is obvious until the attenuation component has been depleted and the ratio near zero.

In **Part B 3** the contamination reduction by microbiological organisms is demonstrated, as NA effects should not solely attributable to physico-chemical factors, but also to microorganisms.

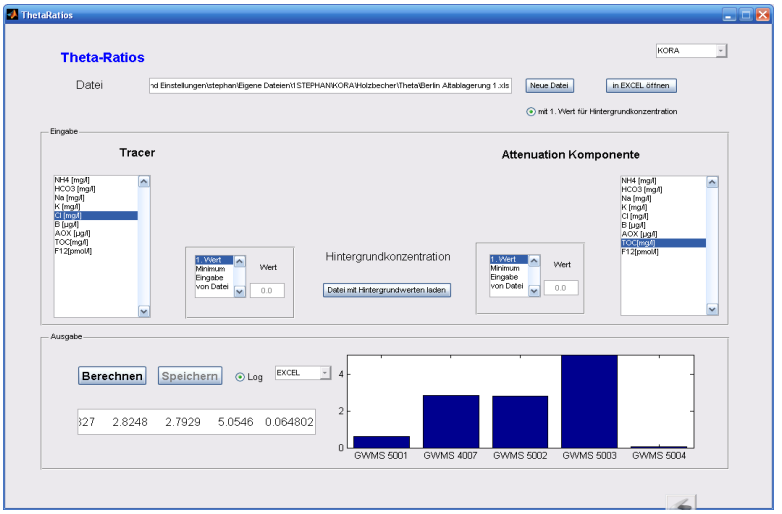

Figure 1. Screen-Shot of the Theta-Value software-program.

The contribution by groundwater microfauna can be checked with the PCR-DGGE method (Kilb 1999, Struppe et al. 2006, Struppe et al. 2010) or more reliable with the newly developed DNA-microarrays (Kühn et al. 2009 and Charlé et al. this issue). This method can be used to differentiate bacteria and archea as well as their activity (Fig. 2). Only when all three methods are positive NA can be legally, based on scientific evidence, used for the reduction of the groundwater contamination.

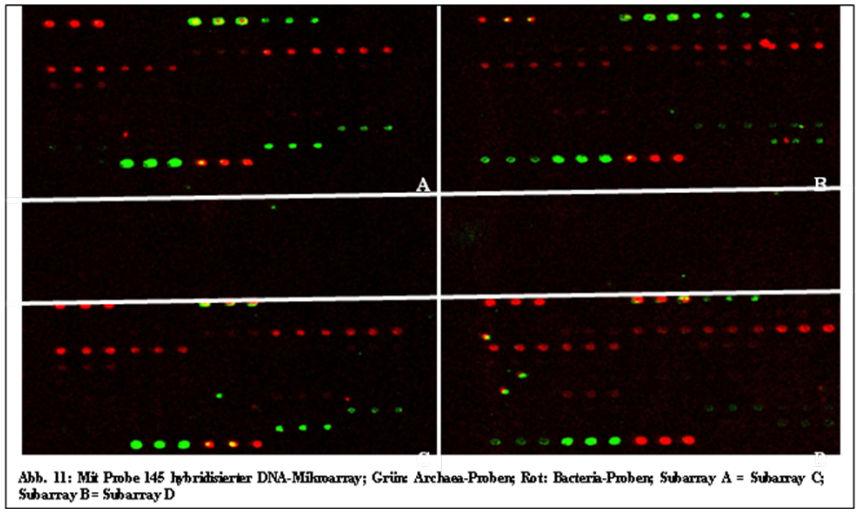

Figure 2. Photo of a DNA-arrays with Archae (green) and Bacteria (red). Their colour intensity equals their activity.

To control this effectively **step C** proposes a monitored natural attention concept (MNA). Based on the results of the investigation indicator-parameters and sampling sites are derived and together with the environmental authorities a target should be defined over which time and to

what extend the groundwater quality has to be improved. The MNA is then used to control the reduction of the pollution for as many years as necessary until the agreed target is reached. This NA-concept provides a cost-effective scientifically proved measure to control and contain groundwater contamination.

PREREQUISITES FOR THE "NA-SCREENING"

To use the "NA-Screening" effectively there are some prerequisite, some of these are useful but some are "conditio sine qua non". To the last category belong the thorough investigation of the groundwater downstream of the pollution. This means sufficient and rightly sited monitoring wells along flowlines, either via direct push or conventionally drilled and a complete analysis of the groundwater samples, using preferably the "groundwater screening". Other sine qua non conditions are that the contaminated site should not be too small and too young, as the NA processes need substance and time to develop.

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