Remediation of soil pollution.
Reduction of the environmental load by determination of the remediation goals

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Abstract:

In the preparation of a remediation programme, the environmental load of the remediation methods is one of the factors, which are important. It is of course important that we choose a method, which results in the smallest environmental load possible. However, choosing a remediation method with low climate impact presupposes that we actually have a number of methods to choose from, which technically satisfy our goal of the remediation. In this presentation we will point out that this prerequisite in a number of cases is not fulfilled and we will propose other solutions to reduce the environmental load by optimising each remediation.

Thermal remediation of a source area in moraine clay illustrates this problem. After the remediation was carried out we have examined whether we would be able to accept a lower degree of remediation than the method offered, which would reduce the energy consumption. This was done by calculating, which effect the different remediation degrees would have had on the contamination level in the plume. The calculations show that a remediation degree of 94% in the source area would have been sufficient. The heating period could have been reduced by one month, the energy consumption by 20%, and the goal of remediation would still be fulfilled.

Excavation of the contaminated soil was also considered. This solution involved a smaller area/volume than the heating solution. However, since the contamination was located under a building, physical constraints and economical considerations did not make it possible to remediate the same area by excavation as by thermal remediation. Calculations show that the energy consumption by excavation is significantly lower, approx. 5 % of the energy consumption in thermal remediation, **but** the goal of sufficient remediation of the xenobiotics could not be achieved. (Thus, the method was “climate friendly”, (but) the total environmental load was larger than for the heating solution.)

Finally natural degradation is the method of remediation, that has the lowest environmental load when climate is considered, but also a method which has to be based on very strong risk assessments. It is the authors' opinion that we today have the tools needed to document the natural degradation and assess the risk of spreading of the contamination. Therefore, the opportunities of using natural degradation should be examined at all major contaminated sites, in order to reduce the need for remediation to a minimum.

INTRODUCTION

When choosing a remediation method, the environmental load is one factor, which must be taken into consideration. In this day and age where it is quite clear that human activities affect the climate, it is important to choose the method with the smallest environmental load possible. However, in the authors' opinion, it is a prerequisite that the method also results in the necessary remediation degree. This requirement often limits the number of methods so much that it is not possible to prioritise minimum environmental load. In contaminations with chlorinated solvents, which form large part of the contaminations that are remediated by the public sector in Denmark, a large part of the source area will often be found in clay soil. If we want both a high degree of remediation and method reliability, we have in fact only two methods to choose from at present (excavation and thermal remediation). Other methods are speculative or unreliable at best.

We will therefore point out another way to limit the environmental load, namely to make a precise calculation of the necessary and sufficient remediation goal. We can hereby limit the remediation to include removal only of the amount of contamination, which is necessary to obtain the condition, which we have decided that we can accept. As a matter of fact, a precise determination of the remediation goal is a prerequisite, if we want to be able to choose at all between methods with different remediation degrees.

To be a little provocative you can say that we often, in connection with choice of remediation method, have made the choice blindly and hoped that the choice was right.

A precise determination of the remediation goal is without doubt the most difficult task in the entire process, and a task, which we until now have had far too little focus on.

A precise calculation of the remediation goal presupposes that the contamination mass is determined and the source area of the contamination is completely outlined. The determination of the distribution and the source strength of the contamination must also be so precise that we reasonably can choose different remediation areas based on different remediation criteria. Apart from this the plume must be determined with great accuracy. Furthermore, the flux of contaminants and possible degradation in source area and plume must be determined. Based on this detailed information, we can calculate the remediation effect on the contamination in the plume and hereby evaluate whether the examined remediation methods will result in the necessary remediation effect to achieve the determined goal. All these initiatives have very low impact on the environment in relation to the execution of the actual remediation, where physical actions are taken, e.g. heating or digging.

Moreover a precise calculation of the remediation goal is a tool that enables us - on a qualified basis – to decide to stop e.g. a thermal remediation before we have achieved the remediation degree, which the method makes possible. An early stop will significantly reduce the clima load.

Finally, the precise determination of the remediation goal as well as a careful assessment of the risk, which the contamination constitutes to the surrounding environment, make it possible that the treatment of the contamination plume and source can be carried out by natural degradation or stimulation of the natural degradation. This approach is particularly interesting, as the natural degradation is the gentlest method with regard to the environmental load on the surroundings.

In the following I will describe the problem in greater detail and illustrate the possibilities to reduce the environmental load in a remediation project which just has been carried out. In this project a source area in moraine clay was remediated by means of thermal remediation.

SCOPE

It is standard practice that the authorities try to reduce the environmental load from remediation of soil contaminations in connection with choice of remediation method. We have demonstrated that this procedure often has its limitations. The purpose of this presentation is to contribute to a reduction of the environmental load by pointing out other solutions.

REDUCTION OF THE ENVIRONMENTAL LOAD

We will illustrate and concretise the possibilities of reducing the environmental load based on a specific remediation, which just has been carried out: A PCE contamination at an earlier industrial dry cleaner, located at Knullen 8 in Odense. The possibilities are illustrated via 2 scenarios. Scenario 1 describes the remediation carried out and the possibilities of reducing the environmental load, if calculations for determination of the necessary and sufficient remediation degree were accomplished before the remediation was carried out. The remediation in scenario 1 was carried out by means of a combination of ISTD and steam. Scenario 2 describes remediation by means of excavation; a solution that earlier was projected and almost initiated, but not carried out due to a budget reduction. Excavation of the contamination only made it possible to remove the most contaminated part of the source area without an extensive demolition of buildings. An extension of the excavation area to include the same area as the heating solution would be so expensive that it was not a realistic possibility. Therefore, the plan was to combine excavation of the most contaminated area with in-situ techniques, such as reductive dechlorination or chemical oxidation on the contaminated areas left, to ensure a sufficient remediation goal.

Contaminant distribution

The contaminants had migrated from a leaking separation tank and sewer drain through 11 meters of clayey till into a high yielding sand/gravel aquifer. The upper 2-4 meters of the underlying sand/gravel aquifer had been determined as heavily contaminated. This level also constitutes the primary groundwater aquifer (Fig. 1).

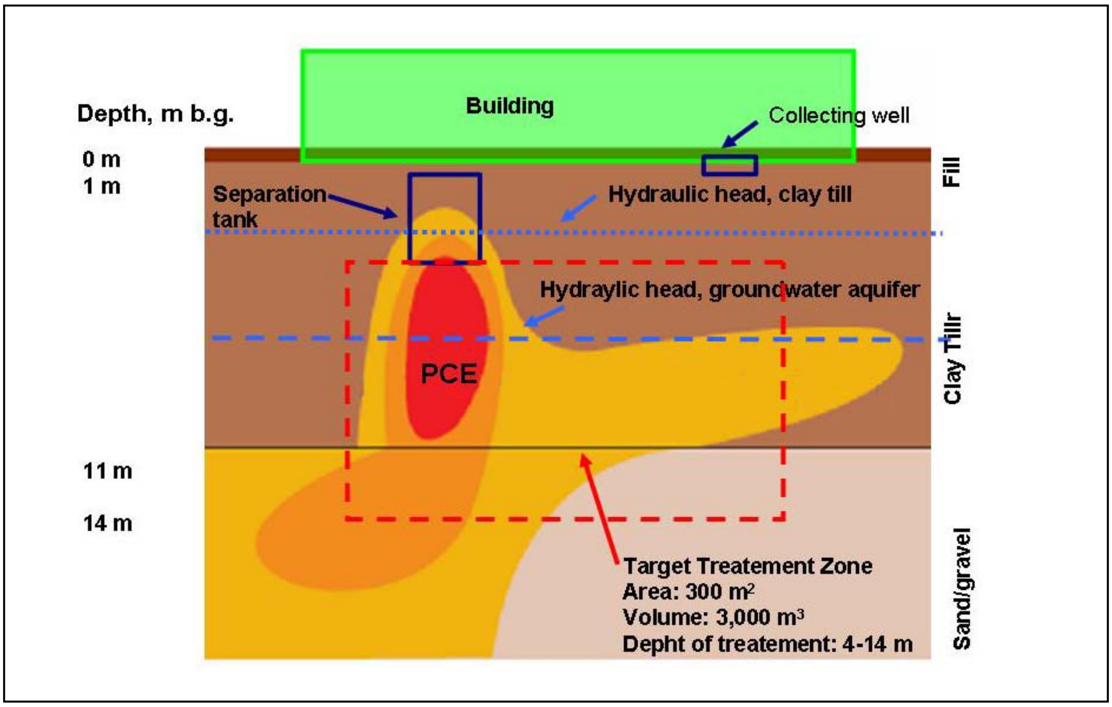

Figure 1. Conceptual Cross-Section and PCE Distribution. The treatment zone is shown as a hashed red line.

The bottom of the separation tank is approx. 4 meters below ground level. The heaviest contamination is found at this level. Areas containing free phases of PCE have been detected in sand lenses and sand layers in the transition zone between till clay and sand/gravel.

Directly under the target area PCE levels up to 97,000 µg/l have been measured in the groundwater. The plume from the site has been detected approx. 1000 m downstream the source area of the contaminant. Throughout the plume the contamination level decreases significantly as a consequence of natural degradation.

Around the contaminant plume, three waterworks are recovering approx. 2 million m^3 of water per year in total.

Scenario 1 (Knullen – remediation with ISTD and steam)
Remediation - Goal and Method
The purpose of remediation of the contamination source at Knullen was to safeguard the groundwater resource and the existing recovery of water in the area, by means of remediation of the source of an extensive groundwater contamination. Remediation of the source area is the first step to achieve this goal. Simultaneously with the remediation, the spreading of the contamination in the groundwater aquifer was investigated to clarify, whether it was necessary also to remediate the part of the contaminant plume close to the source.

A precise size of the acceptable plume length after the effect of the remediation was not determined. Based on model calculations, the plume was expected to shrink to approx. 300

meters. In the evaluations carried out in the following sections of this article, the initial acceptable treatment zone was fixed at 300 meters.

Remediation method

The remediation was carried out by means of heating. The heating took place by combining two methods. The clay layer was heated by means of heating units (ISTD) and the under lying sand layer by means of steam. The remediation area comprised an area of 300 m^2 of which approx. 90% was located under buildings. The remediation area was determined based on a limitation criterion of 10 mg/kg PCE.

The success criteria were determined to be the remediation degrees, which the methods were expected to provide, i.e. 99 % in the clay and 95 % in the sand layer.

Remediation results

During the remediation, a total of approx. 3500 kg of PCE and approx. 500 kg of degradation products were removed. A remediation degree of 99.7% in the clay and more than 95% in the sand layer was achieved. In total, a remediation degree of more than 99% was achieved in the remediation area. The remains of the contamination left in the remediation area were calculated to approx. 10 kg. Outside the actual area, the soil is still a bit contaminated, just as contamination still can be found in the plume. The remaining contamination was estimated to approx. 100 kg in total.

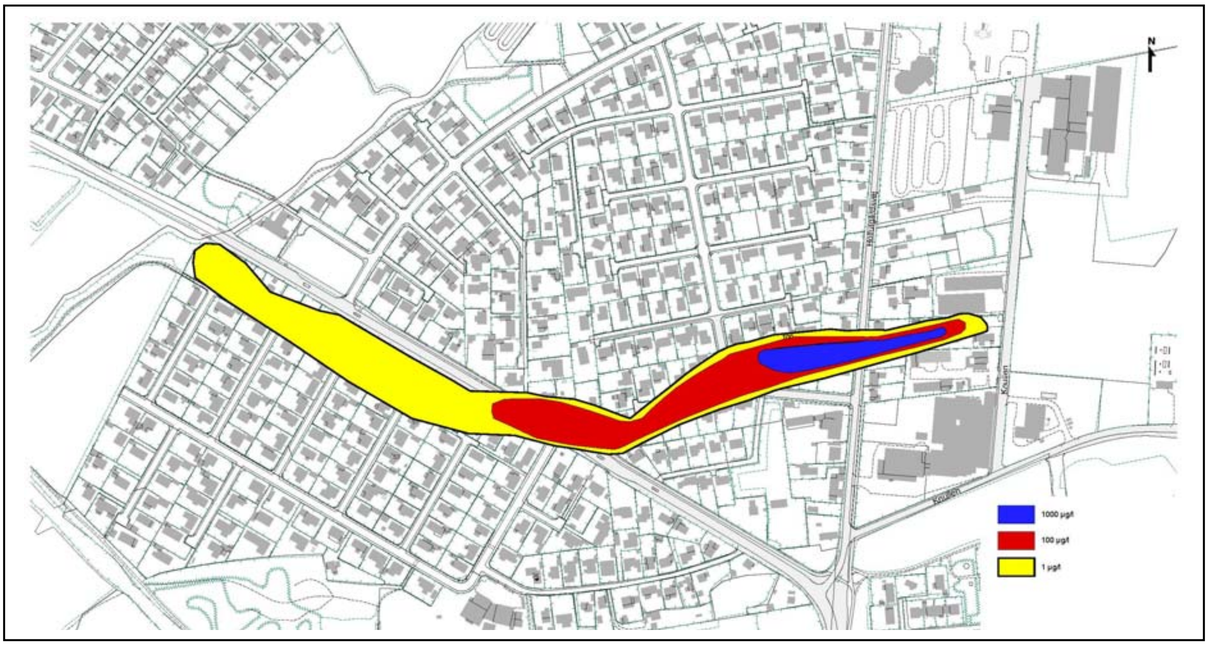

Figure 2. Remaining contamination in and around the remediation area and in the plume.

Determination of the necessary and sufficient remediation degree

Determination of the necessary and sufficient remediation degree was carried out by comparing the calculated effects of the different remediation scenarios on the contamination in the plume. For each scenario, the effect was calculated for the time periods 10, 50, 100 and 200 years after the remediation was carried out.

The calculations were carried out in 2 steps. The first step was to calculate the washing out of contamination from the clay soil to the groundwater aquifer. The calculations were based on concentrations measured in the soil. The soil concentrations were converted into pore water concentrations by means of fugacity calculation, but maintaining a maximum concentration of 240 mg/l in the most contaminated areas. Thus, the calculations only included dissolved contaminants. The percolation was set to 100 mm/year. This is almost double the percolation normally used in model calculations. The reason for this was that warm wastewater containing PCE had seeped through the soil over many years, which had changed the soil structure with increased permeability as a consequence.

Calculating with equilibrium concentrations in the soil phase, the percolation model is basically conservative for all scenarios, where remediation has been carried out. Only when calculating before remediation, the model does not have to be conservative, as it does not include transport of free phase PCE.

For verification of step 1 in the calculation model, the calculated dissolved concentrations for a scenario without remediation were compared to the contents found at the contamination investigation, and the calculated percolation of PCE to the groundwater aquifer was compared to the flow, which was determined in the groundwater aquifer. The calculation shows that:

	Observed conditions (average concentration)	Calculated without remediation (average concentration)
PCE in pore water in clay (mg/l)	2,7 - 240	185
PCE in primary aquifer (mg/l)	1,1 - 97	50
PCE flow in the groundwater aquifer kg/year	6	6

Step 2 was calculated with a substance transport model with degradation. The calculations were carried out with 2 degradation rates for PCE, a high rate and a low rate. In order to verify the actual degradation rate in the aquifer, calculations with both rates were compared with the actually observed contamination conditions in the plume.

Figure 3. Calculated plume without remediation, low degradation rate.

The calculation with low degradation rate corresponded very well to the actual conditions. Therefore, calculations with low degradation rate formed the basis of the effect evaluations of different remediation scenarios. It was evaluated that the model thoroughly described the effect differences between the scenarios.

The expected effect of the remediation on the contaminant plume
The effect of the 99% remediation carried out in the source area is shown in figure 4, corresponding to remains of 35 kg PCE left in the source area.

Figure 4. Contamination distribution 50 years after the 99% remediation in the source area.

The figure to the left shows the plume based only on the washing out of the remaining contaminant in the source area. The figure to the right shows the original plume and the contribution from the remaining contaminant after remediation.

As you can see a 99% remediation means that the washing out contribution from the source area to the plume would be very small compared to the amount of contamination already found in the plume. The calculation shows that the remaining contamination in the plume for many years to come would constitute the dominant part compared to the contribution from the source area. A significant reduction of the plume distribution within a short period of years would therefore require a remediation in the plume to be initiated.

If the remediation carried out in the source area is supplemented with a remediation initiative in the plume, which removes at least 70% of the contamination, it is estimated that the objective of a maximum plume distribution of 300 m. can be fulfilled.

Significance of a lower remediation degree
Figure 5 shows how much bigger the washing out contribution from the source area would be, if the heating time in the clay was reduced by 30 days. Based on the remediation procedure it was calculated that such a reduction would have resulted in a reduction of the remediation degree achieved, from 99% to 94%.

Figure 5. Contamination distribution 50 years after 94% remediation in the source area.

The figure to the left shows the plume based only on the washing out of the remaining contaminant in the source area. The figure to the right shows the original plume and the contribution from the remaining contaminant after remediation.

A remediation degree of 94% corresponds to leaving 210 kg of PCE in the source area. The washing out contribution from the source area would also in this situation be smaller for many years than the contribution from the remaining contamination in the plume. However, the recontamination contribution from the source area would be so big that the objective of a maximum plume distribution of 300 m could not be fulfilled, even if a remediation was carried out, which removed 70% of the contamination content in the plume.

If the objective of a maximum plume distribution of 300 m was to be fulfilled, a larger and prolonged initiative/remediation would be necessary. On the other hand the wash out contribution is not bigger than it could be considered to expand the treatment zone, and thus avoid a prolonged remediation initiative.

Possible reduction of the environmental load on the climate
A reduction of the heating period by 30 days would have resulted in a saved amount of energy of 410 MWh out of a total energy consumption of 2000 MWh. Thus, a reduction of 30 days of the heating period would have resulted in a reduction of the energy consumption of 20%. Unfortunately the economical saving would only be about 7%.

However, the reduced remediation period would imply that the length of the treatment zone (the maximum length of the plume) would exceed the objective of 300 m. If the objective was to be fulfilled, a continued effort/remediation in the plume would imply that the reduction of the environmental load would be smaller and the costs would increase.

Scenario 2. (hypothetical - Knullen remediation by means of excavation and reductive dechlorination)

Alternative remediation method
The alternative remediation method included excavation of the main source area, in total approx. 750 m^3 of soil. This method included the excavation itself, transportation as well as delivery of uncontaminated soil.

It was calculated that in relation to the remediation area in scenario 1, a remaining contamination of 500 kg PCE would be left in the clay together with an amount of contamination in the underlying groundwater aquifer in order of magnitude 100 kg.

Expected effect of remediation
Excavation of the main source area would remove the contamination to the extent that 500 kg PCE were expected to be left in the remaining part of the source area. Contamination in the underlying aquifer is presupposed removed by additional remediation action. The washing out contribution from the remaining contamination in the clay layer to the plume appears from figure 6.

Figure 6. Contamination distribution 50 years after excavation of the contaminated soil from the main source area including remediation of the groundwater aquifer.

The figure to the left shows the plume based only on the washing out of the remaining contaminant in the source area. The figure to the right shows the original plume and the contribution from the remaining contaminant after remediation. It appeared from the simulation that the recontamination contribution largely corresponded to the conditions without remediation, c.f. the simulation result in figure 3.

If the remediation by means of excavation was to fulfil the objective of reducing the distribution of the contaminant plume, a long-term effort would have been necessary in the source area as well as in the plume.

Possible reduction of the environmental load

The energy consumption of excavation would have been significantly lower than the heating solution, as the energy consumption would have been approx. 50 MWh, in other words only approx. 5% of the energy consumption of the heating solution. All other environmental loads of the two methods were evaluated to be almost the same.

However, the solution must be combined with a long-term effort with In Situ treatment of the remaining contamination in the source area as well as initiatives in the plume. Although this method has a very low consumption of energy, the method is not to be recommended if the goal is to reduce the overall environmental load.

CONCLUSION AND PERSPECTIVE

It is possible to reduce the environmental load in remediation of soil contaminations by defining the contamination conditions, you want to obtain, and by determining – based on calculation – exactly how much contamination that has to be removed in order to fulfil the objective.

Based on a specific thermal remediation, calculations have shown that it would have been possible to reduce the energy consumption by 20%, if the remediation objective was not defined as the upper most potential of the method, but only the remediation degree that precisely fulfilled the objective of the remediation.

On the other hand, when looking at the durability of the solutions as well as risks and economy, not only advantages were achieved. Reducing the heating period causes that you ether must be willing to prolong the treatment zone or to carry out a long-term effort/remediation in the contaminated plume with extra costs and environmental load. The costs of such an effort were not calculated, but an immediate evaluation indicated that they might very easily exceed the savings of the reduced heating period.

A prerequisite for this being a solution is that it is possible to calculate the remediation goal with such a degree of certainty, that the client feels confident about e.g. stopping a remediation, when the calculated goal is achieved, even though the remediation method makes an even better result possible. At remediation with heating there seem to be relatively large possibilities of reducing the energy consumption and with this the environmental load on the climate. Unfortunately, the problem is that a corresponding economical saving is not achieved in the remediation costs. So the dilemma is: how much regard should be paid to limitation of the environmental load, when this is to be compared to

1) the risk that the remediation degree has been set too low
2) the risk that the actually achieved remediation degree is lower than expected, and
3) the reduced remediation produces only a marginal economical saving.

These questions cannot be answered until months or years after the remediation is concluded.

This solution also requires that the authorities are willing to accept a contamination plume, which has a distribution exceeding the limit of 100 meters, which the Danish Environmental Protection Agency has determined as an instructive limit. The reason for this is that natural degradation or stimulated natural degradation most often requires a treatment zone a little longer than 100 meters. The fact that the local counties – the authority responsible for the execution of public remediation in Denmark – often accept contaminations, which spread longer than the 100 meters limit, does not mean that it is standard practice to allow exceeding It has been investigated whether of the limit in a specific remediation case. So far it has not been common practice in the Region of Southern Denmark to make a precise determination of the length of the treatment zone to natural degradation, who has preferred to wait to see what could possibly be achieved.

It has been investigated whether a reduction of the environmental load had been possible, if a solution less detrimental to the environment was chosen, namely excavation of the contaminant soil. Calculations show that the excavation solution would not result in a significant reduction of the extension of the contamination. If the objective of reducing the extension of the contaminant plume substantially was to be fulfilled, a long-term effort in the source area as well in the plume would be necessary. Our evaluation is that excavation of the contaminated soil in this case is not a possible solution although the energy consumption of this method is low compared to the energy consumed in the heating solution.

Futhermore, if the goal of a treatment zone of 300 meters could be expanded, maybe even so much that no active treatment was necessary, it could instead be considered to leave the reduction of the contamination to leaching and natural degradation. Such a solution has been chosen at another site in the County of Southern Denmark, namely Ringe Tjære- og Asfaltfabrik (RTA), which is a former tar and asphalt plant. At this site extensive studies have been carried out documenting the natural degradation. The studies show that the tar decomposes within a distance of 250 meters from the source zone. The cost of the study of natural degradation has been approx. 5 million Danish kroner. Furthermore, the cost of monitoring is expected to amount to 1 million Danish kroner. This is to be compared to a remediation cost of at least 15 million Danish kroner.

There is no doubt that the necessary investigations to document natural degradation have a lower environmental load than would have been the case if the site was remediated, by for example thermal remediation.

The question is whether we could have done the same at the Knullen site? The answer is that it would have required a lot of courage of the decision makers together with a very comprehensive study and risk assessment because of the complex situation regarding the water supply in the area.

It is the authors' opinion that we today have the tools needed to document the natural degradation and assess the risk of spreading of the contamination. Therefore, the opportunities of using natural degradation should be examined at all major contaminated sites, in order to reduce the need for remediation to a minimum.