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Short Papers and Abstracts

Notes

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Session A

Circular Economy

Keynote Speaker: Circular economy –"When others see an end, we see a beginning!"- *Pär Larshans, Chief sustainability officer, Ragn - Sells, Sweden*

Eco-innovative SMEs as facilitators in circular economy transitions towards sustainable mitigation of contaminated sites risks - *Jarno Laitinen, Doranova, Finland*

Implementing the concept of circular economy by long term land use planning in West-Harbour, Finland - *Kimmo Järvinen, Ramboll, Finland*

Keynote by Pär Larshans:

Circular economy –"When others see an end, we see a beginning!"

The driving force behind urbanization and change in demographics and living standards will have a huge impact on how cities expand in the 20 years to come. Restoring land areas while transferring the society into a fully functional circular economy needs to be complemented with a detox step in preventing that the circular model spreads toxin back into society. The need of long term planning with procurements that allows innovations must also have a society that strives for partnership. In this landfills will be our next circular station NOT an end station.

ECO-INNOVATIVE SMES AS FACILITATORS IN CIRCULAR ECONOMY TRANSITION TOWARDS SUSTAINABLE MANAGEMENT OF CONTAMINATED SITES RISKS

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Abstract

Circular economy represents a new narrative built upon the promise to solve both ecological and economic problems, framing increased ecological resilience and social change beneficial for business and thus for the economy and society at large. In the past years, eco-innovative SMEs and circular businesses have been the key contributors addressing ecological issues from both the perspective of economy and society. This presentation expands the concepts of circular economy to contaminated sites remediation and discusses how eco-innovative SMEs and new circular business models can facilitate a transition towards more sustainable mitigation of contaminated sites risks. The transition is explored by a pathway oriented scenario analysis using the Transition Space Matrix model. The analysis focuses on a systemic transformation, hence the focus is in the 34 year timeframe of 2016 – 2050.

Introduction

There is an increasing support among policy-makers and researchers for the notion raised under the banner of sustainability, that transition to a resource wise and low carbon economy, by circular or green economy is needed in the near future. These new narratives promise to solve both ecological and economic problems, and frame increased ecological resilience and social change beneficial for business and thus for the economy and society at large.

By perceiving circular or green economy as means to an end - not the end itself, we can focus on transition as a process. Ecologists and economists have traditionally conceptualized transitions as changes from one position to another, but broader conceptualization of transitions in the context of systems has received increasing attention over the past years (e.g. Bergh et al., 2011).

Systems in general are entities comprising of various interacting elements. Most well-known (though ambiguously) approaches to systems are the ecosystem and the financial system. More appropriate models originate from technology and economics, namely large technical systems, sectoral systems, technological innovation systems, and socio-technical systems (Geels & Kemp, 2007). Whereas the former focus primarily on innovation as means for businesses and industry to achieve competitiveness and economic growth, socio-technical systems are first and foremost interested in how new practices of production and use emerge and retain in society (Bergh et al., 2011; Coenen & Lopez, 2010.)

In the socio-technical context, transition is seen as a set of processes that lead to far-reaching fundamental changes in large systems like energy, transportation, construction, agriculture or water supply. These changes involve a broad range of actors and typically unfold over considerable time-spans. In the course of such a transition, new products, services, business models, and organizations emerge, partly complementing and partly substituting existing ones. Not only do the technological and institutional structures change, but also the perceptions of consumers regarding what constitutes a particular service (or technology) is transformed. In the specific context of socio-technical systems

transition towards sustainable development, it is often called in short sustainability transition (Bergh et al., 2011; Markard et al., 2012; Jorgensen, 2012.).

Materials and Methods

To evaluate sustainability transitions towards circular economy in contaminated sites risk management transition space matrix (TSM) is used. The tool allows to model and explore how large socio-technical systems transition towards more sustainable. It models reality by applying the multi-layer perspective (MPL), which is a framework to explain the hierarchy and dynamics of socio-technical systems (Geels, 2010). The transition within MPL is analyzed and explored by double flow scenario (DFS), which is an iterative tool combining forecasting and backcasting (Gaziolusyou et al., 2011).

The MLP is a systemic model of three inter-connected levels of socio technical systems that are defined by the metaphorical notions of 'landscape', 'regime' and 'niche', which implicitly links between macro-, meso- and micro-level theories well known to economic and sociological definitions of hierarchy. The landscape consists of slow changing external factors providing gradients, regimes account for stability of existing technology and niches for the generation and development of (radical) innovations. (Geels, 2001; Jorgensen, 2012)

The DFS combines both front- and backcasting. Forecasting is a method that describes the present and develops future narratives based on this, whereas backcasting develops a vision and 'backcasts' the narrative to the present. In the model time is divided to present, mid- and long-term. Present describes today (reality) based on historical data and forms the baseline of the analysis. Long-term describes the shared vision (goals and targets) of the aspired future states and mid-term forms the core of analysis. This in-between is where the transition actualizes.

The TSM is constructed by combining the MLP and DFS to a 3 x 3 matrix, where the rows represent the hierarchical structure of the MLP landscape, regimes and niches and the columns the DFS division of present, mid-term and long-term.

Results

The analytical model is built on four stages, namely (1) *Baseline*, in which the environment, concepts and key driving forces are identified; (2) *Vision*, in which the goals and targets are envisioned; (3) *Transition*, in which the baseline and the vision are integrated in the TSM; and (4) *Roadmap*, in which the identified transition seeds, pathways and obstacles are transformed into a roadmap.

(1) Baseline

The Finnish national register holds information on over 25 000 potentially contaminated sites of which over 15 000 are not sufficiently investigated to define whether they are contaminated, and is there need for risk management activities. Currently it is estimated that over 11 000 sites will require remediation (SYKE, 2013).

The existing volume of contaminated sites remediation is between 250-300 sites per year and average costs of investigation and remediation per site is expected at EUR 200 000. Majority of remediations are done *off-site* by excavations and disposal, and annually only 10-15 (< 5%) by other *in situ* and *on-site* methods. The excavated soils are mainly being re-used as-is in landfill structures. Most common reason

for initiating private sector remediation are changes in land planning or construction works. The public sector accounts for 15 % of all remediation works.

To address this specific issue Finland has in 2015 launched a new contaminated sites risk management strategy. It is founded on a vision, that both contaminated sites risks and remediation, must be managed sustainably and cost effectively. The objective of the strategy is to manage sustainably the environmental and health risks imposed by the contaminated sites by the year 2040. In relation, the current Finnish sustainable development strategy (ME, 2013) defines in its vision that in Finland “*the carrying capacity of nature is not exceeded and natural resources are used in a sustainable manner*” by “*an economy that is resource-wise*”. The government has also outlined as a country strategy (MEE, 2014) to develop Finland a global cleantech superpower.

At present, the companies operating on the remediation market are mainly national and multinational consulting companies, contractors and remediation specialists. The volume of international exports by domestic actors is very small.

(2) Vision

Finland in 2050 is a sustainable, resource wise state that has a strong circular economy based operating environment. Contaminated sites risks have been systematically addressed, key environmental and health risks have been identified and managed by 2040 and majority of contaminated sites have been remediated by 2050. The public perception of contaminated sites related risks has transformed to a realistic acceptance, allowing for innovative applications of risk management to be developed. The states proactive support in sustainable land management has supported growth and internationalization of eco-innovative cleantech SMEs, enabling them to develop and commercialize new technologies and business models for pollution management together with research organisations. This has integrated Finland as one of the international knowledge and innovation centres in contaminated land management. Solutions for contaminated land and pollution management innovated and applied in Finland are being exported globally by a number of internationally operating SMEs benefitting from the strong ‘Clean Finland’ country image.

(3) Transition

The transition space matrix describes the actors, actions, risks and opportunities (hereinafter *key factors*) at niche, regime and landscape levels. In landscape the key factors arise from *paradigm forces*, *global pressures*, *macroeconomic*, and potential *lock-ins*. In regime level the key factors include *socio-technical systems* such as waste management and construction, and *political*-, *industrial*-, *economic*- and *socio-cultural regimes*. In niche level the factors include *change agents*, *socio-technical*- and *industrial niches*.

(4) Roadmap

The roadmap is constructed on the basis of the TSM. It is created by elaborating the key factors identified to a timeline and represents the transition pathway. The resulting roadmap includes the following stages: (1) *policy formulation*, where the domestic legislation and international policy on soil protection and raw material efficiency are enforced and clear long term strategies are created in coordination to support the transformation; (2) *industrial structuring* where a number of SMEs acknowledge the direction of development and begin building networks and developing solutions for future applications; (3) *resource wise economy*, that establishes a market for circular business models and sustainable means of operating, and; (4) *sustainability leadership* where the achievements of

Finland in managing soil protection is recognized internationally and the expertise of the applications are sought for solving problems in a wider territory.

Discussion

Circular economy transition towards sustainable management of contaminated sites risks is possible within the scope of analysis presented. The key actors in the transition will be eco-innovative SMEs, universities, TROs and the proactive state. To achieve a resource wise economy and create a cleantech segment that can act as a global sustainability leader, a domestic market and industry must be first created. The key initiators of this transition will be the landscape forces that insert pressure on the existing regimes and allow for new niche solutions to emerge. These new solutions help solve the external costs that do not enter the private costs of the polluter, create a circular operating environment that links ecosystem services with business benefits and leverage the value of soil and nutrients.

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IMPLEMENTING THE CONCEPT OF CIRCULAR ECONOMY BY LONG TERM LAND USE PLANNING IN WEST HARBOUR, FINLAND

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Abstract

West Harbour – Jätkäsaari - in Helsinki is an old cargo port, which is currently built as a residential area for 18 000 people. In the 80 hectares site, the soil level will rise locally even up to 7 meters. New land filling has been done in a 20 hectares area, and 2.5 million m³ of seabed sediments has been dredged. The harbour area, built on old sea bottom, is contaminated mainly from deposition of construction waste for land fillings, particularly during 1930 -1960. The main contaminants at the site are heavy metals, heavy oil, and PAH-compounds. The surface layer of the seabed sediments contains typically PCB, TBT and heavy metals.

The aim was to increase the resource efficiency of the construction and to decrease the transport of soil and construction material through the city, i.e. avoiding both transporting soil to treatment plants and importing soil to the site. For this purpose, environmental permits were applied for the recycling of contaminated soil and sediments to be utilized in construction of a large park area. Concrete was utilized in new land fillings, which is also regulated by the environmental permit. The estimated economic benefits of the recycling are approximately 2 million euros.

Introduction

The contamination was accounted for in the Master plan of 2006, in which a large park was planned above the areas where most of the heavy metal contamination occurred. In addition, a sports park was located above an old land fill (mainly construction waste). The City plan of the park (4.8 hectares) was approved in 2009 and included a 1.5 hectares area for recycling of contaminated soil. Helsinki received in 2009 and 2014 the environmental permits for two different parts of the park area. Contaminated soil containing hazardous waste, volatile organic compounds and organic waste are not utilized.

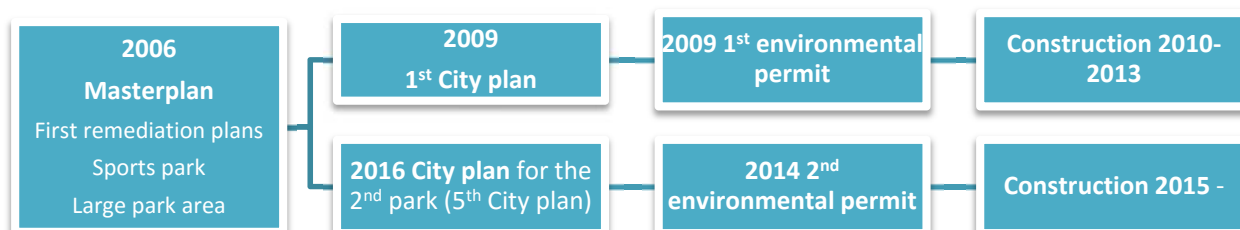


Figure 1 The process started before approval of the Masterplan in 2006

The environmental permit also included the permit for soil remediation of the entire City plan area (30 ha), and a permit to recycle construction waste (concrete, asphalt and tile) in the construction. As the cargo port was relocated, many of the buildings were torn down, and the

concrete was recycled at the area. The environmental permit of the second park allows for deposition of contaminated soil from other construction sites in Helsinki city as well. The construction of the West-Harbour is scheduled to finish in 2025.

Material and Methods

The potential ecological and health risks of deposition of contaminate soil to the park area were assessed, both for the situation during construction and after construction. The side banks of the park were constructed from blasted stone and from recycled asphalt removed from the site. To redirect rain water without leaching of harmful substances, the surface structure of the recycling area consists of a sloped subsurface drainage system with an impermeable bentonite mat (Figure 2). The surface structure of the park was completed in 2013. The second park (Figure 3), which construction began in 2015, follows a similar structure and environmental regulations as the first one. The surface water and infiltration water is monitored during the construction phase. In addition, the groundwater around the park is monitored.

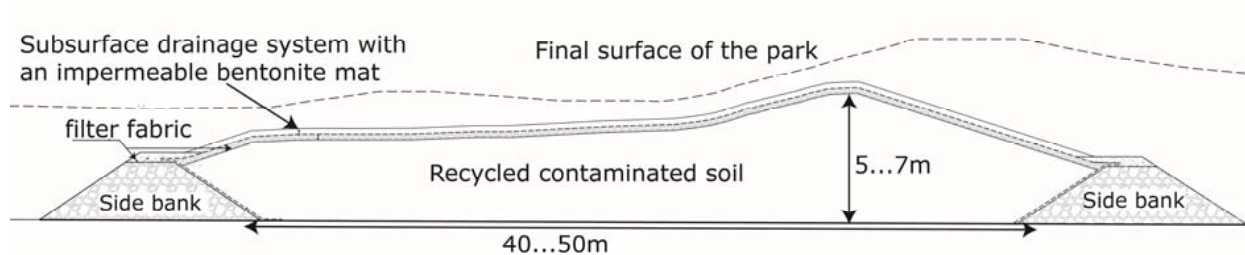


Figure 2 The structure of the park area.



Figure 3 The situation at the site in 2015. Resource efficient construction requires a large enough short-term storage site for the soil and other materials.

The sediments containing harmful substances were stabilized to be used in the park construction. The suitability of geotextiles and drainage pools were experimented to drain the cohesive-sediments. The latter proved more efficient, although the runoff was small and the main drying mechanism was evaporation from the top layer. Therefore, the sediments were stabilized.

The saves in carbon dioxide emissions and fuel consumption were estimated with emission class Euro 4, based on the length of the route, vehicle type, and amount of transported soil. 90 % of the travel was estimated to be outside the city area, and the truck was assumed to return empty.

Results

By the end of 2015, 109 100 tons of contaminated soil was excavated, of which 8 100 tons had been transported to deposition sites or treatment plants outside the area (Figure 4). The amount of recycled soil would correspond approximately to 2300 truckloads, 700 000 kilometres and 300 000 litres in fuel resulting to 740 000 kg in carbon dioxide emissions if the material was transported outside of the construction site (see table 1). By the end of 2015, 40 % of the second park area’s capacity limit of the environmental permit was filled.

Table 1. Estimation of saves in fuel consumption and carbon dioxide emissions contaminated soil transported to deposition sites instead of utilizing it on site at West Harbour.

	Excavated contaminated soil	Soil imported to the site	Sum
ASSUMPTIONS			
Amount of transported soil, t	93 000	93 000	
Truckload*, t	40	40	
Amount of truckloads	2 300	2 300	
Length of the route, km	100	50	
- of which in the city, km	5	5	
RESULTS			
CO2-emissions, kg	490 000	250 000	740 000
Fuel consumption, l	200 000	100 000	300 000

*Emission class EURO 4

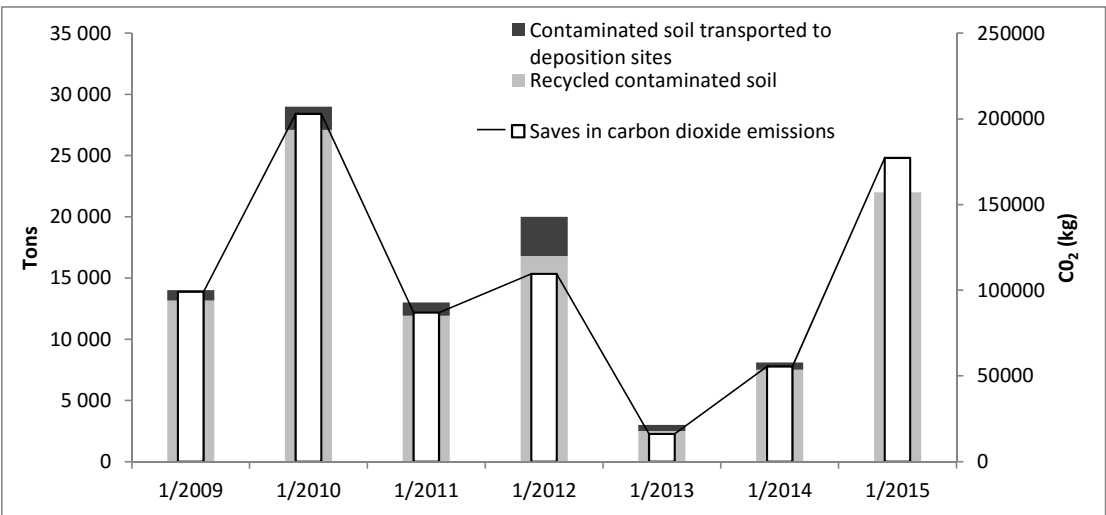


Figure 4 Tons of excavated soil recycled at the area or transported to deposition sites outside the area, and saves in carbon dioxide emissions due to recycling of soil.

Altogether 120 000 m³ stabilized sediments have been used mainly outside of West Harbour and in a couple of other parks in Helsinki. By the time that West Harbour is ready 2.5 million m³ of seabed has been dredged, and 6 million m³ of new land filling has been completed. 11 000 m³ of concrete was used in the land fillings. The amount is small considering the total amount of material required for the land filling. However, recycling of concrete has saved costs compared to transporting it to a landfill.

Discussion and Conclusion

Compared to conventional dig and dump soil remediation, recycling of contaminated soil and sediments during the first construction phase by 2012 has saved circa 270 000 litres of fuel and 680 000 carbon dioxide emissions, and by 2015 when the second phase had started 740 000 in carbon dioxide emissions was saved by recycling of contaminated soil. Due to recycling, less than 10 % of excavated contaminated soil was transported to deposition sites outside the construction site.

The extra costs of building the park result from the construction of the surface structure. If the costs are lower than the costs of transport and deposition of the soil, then it is more cost-worthy to recycle rather than export soil to deposition. Detailed cost-analyses were conducted in another area, Vuosaari port, where a sound barrier landscaped as a hill was constructed from on-site contaminated soil. Cost-analysis revealed that recycling of contaminated soil saved approximately 15 €/ton compared to conventional dig and dump soil remediation. With similar cost-analysis, the saves in West-Harbour would be approximately 2 million euros.

Resource efficient construction may save money and natural resources, but the down-side is that it requires long term planning both do to city planning and application process of the environmental permit. The design started in the land use planning, and required close co-operation with different city offices, environmental planning, geotechnical design, and landscape design. The recycling of contaminated soil and sediments is restricted by lack of standards in Finland and requires at the moment an environmental permit in each case. The approval of the permit may take from one to two years. Therefore, new regulations are needed to encourage sustainable building, which is currently in planning phase by the Ministry of the Environment of Finland.

Acknowledgements

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Notes

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Session B

PFAS

The remediation of PFAS contaminated airport soils - *Paul Cappelen, Norwegian Geotechnical Institute, Norway*

From point sources to the Baltic Sea - fate of perfluoroalkyl acids in the aquatic environment with a focus on mass balance studies - *Marko Filipovic, NIRAS, Sweden*

Lessons learned and challenges encountered after characterizing 100 Poly- and Perfluoroalkyl substances - *Dave Woodward, Aecom, USA*

Mapping of PFAS contamination beyond firefighting sites - *Katerina Tsitonaki, Orbicon, Denmark*

THE REMEDIATION OF PFAS CONTAMINATED AIRPORT SOILS IN NORWAY

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Abstract

Aqueous film forming foam (AFFF), has been used historically at Norwegian airports (and indeed worldwide) and as such has resulted in widespread contamination of groundwater and soils with a multitude of per- and polyfluoroalkyl (PFAS) substances. The behaviour of PFASs in the unsaturated soil zone and the way in which this affects contamination of underlying groundwater is relatively unknown. PFAS are considered as persistent, highly mobile and degradative resistant compounds and as such their environmental presence is ubiquitous.

One of the most investigated PFAS is PFOS (perfluorooctanesulfonate) as this compound drives regulation in many countries. In Norway, the Norwegian Environment Agency has been instrumental in the gradual phase out and ban of the use of PFOS and also in the suggestion of guideline values for site clean-up. PFOS was banned in AFFF in Norway in 2007 and from 2011 all AFFF used in Norway was per- and polyfluor compound free. The Norwegian Environment Agency has published a guideline value for the concentration of PFOS in soils that cannot be exceeded of 100 µg/kg. This very low target value in soil drives remediation efforts.

Material and Methods

In order to suggest suitable methods of remediation that comply with environmental legislations it is important to obtain an understanding of the behaviour of PFOS in the environment. Cleaning up to such low concentrations is technologically, logistically and chemically challenging. This work was carried out as a feasibility study for the remediation of a soil from a Norwegian airport and contaminated with PFAS. The airport has been in military use since 1912 and in commercial use since 1998. It is located above Norway's largest groundwater reservoir (3-4 m depth), which is connected to local rivers. Historical use of AFFF at six fire-fighting training platforms without sufficient physical barrier to the soil and water below has resulted in spreading of PFAS. Today, water barriers, groundwater pumping wells, and runoff collection systems are used and PFAS contaminated runoff is treated using activated carbon (AC) filtration systems that were installed in 2015. When the AC filters reach sorption capacity they are incinerated.

To begin the feasibility study, sorbent amendment using AC and two other materials was tested in order to decipher whether treatment efficiency seen for water samples could be replicated for soil. Soil samples were taken from the currently used firefighting training facility and the concentration of a variety of PFASs was quantified. Concentrations of PFOS ranged from 6.4 µg/kg up to 2600 µg/kg and all of the soil samples were sandy in nature. With the Norwegian guideline value of 100 µg/kg, many of the samples were observed to exceed this. In order to test the success of sorbent amendment, AC, compost soil (C) and montmorillonite (MM) were added to the soil samples at a 3 % weight dose and then the samples were exposed to a shake test (following Norwegian standards). The test was carried out at a L:S ratio of 10 and the leaching of PFOS both for the unamended and sorbent amended soil and the leaching of PFOS was quantified. Figure 1 shows the experimental set up of the shake test.



Figure 1: soil from the fire fighting training facility containing PFOS, and water being mixed end over end for a period of 8 days. Following this the sample is filtered and the water analysed.

Results

Results from the tests showed that the leachability of PFOS in soils without sorbent amendment was up to 100 % of the total concentration. For both the total concentrations of PFOS and the leachable concentrations there were no clear trends with soil properties (K_D , organic matter content, Ca content, Cl content, pH, Mn content, Fe content or SO_4 content). Soil-water partitioning coefficients were calculated for the unamended soil and were low for these samples (2 to 50 L/kg). Figure 2 shows some examples for the total concentrations of PFOS measured in the soil samples and soil properties.

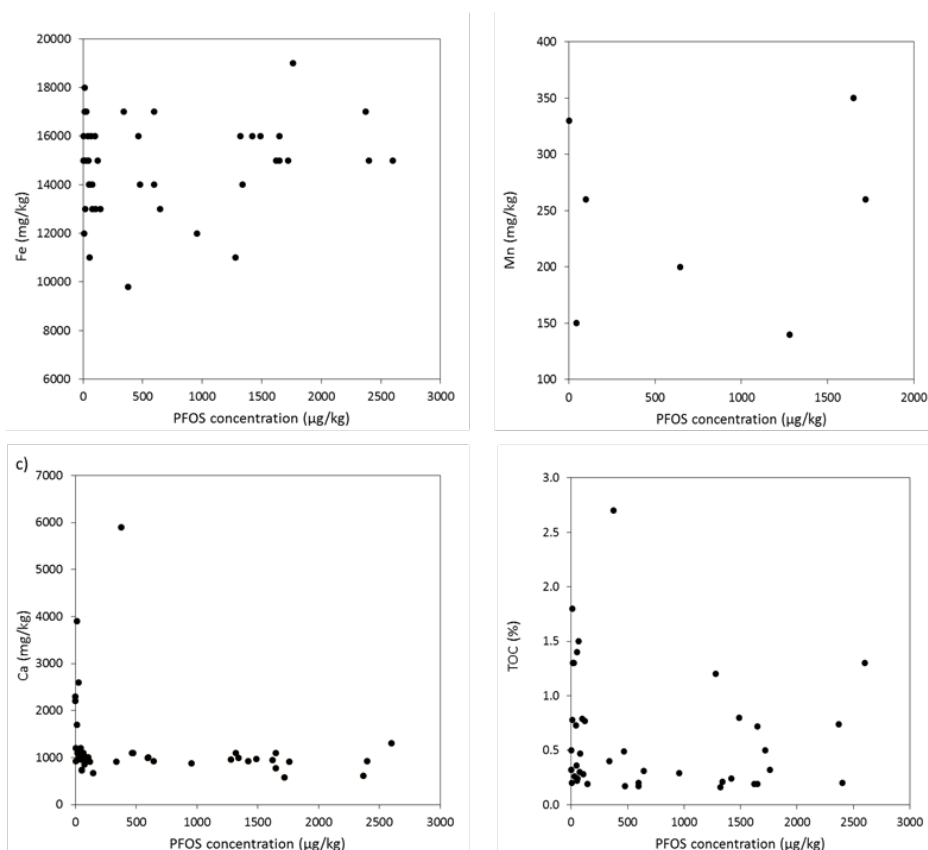
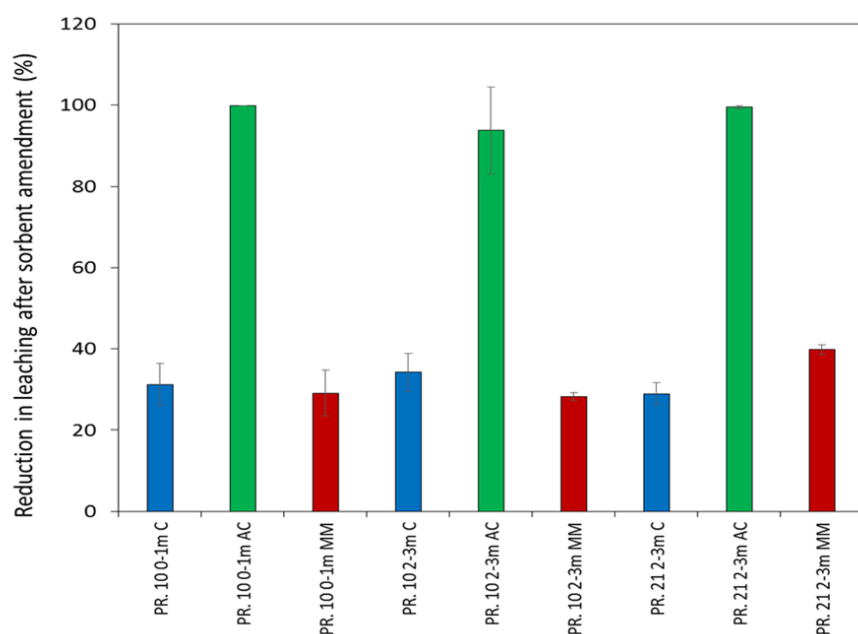


Figure 2: Correlation between soil PFOS concentrations ($\mu\text{g/kg}$) and a) Fe (mg/kg), b) Mn (mg/kg), c) Ca (mg/kg) and d) TOC (%).

Results of the shake tests for the sorbent amended samples showed that all sorbents were able to reduce the amount of PFOS leached from the soil. AC has the highest sorption capacity for PFOS (and other PFAS), with 99.9 % reduction in leaching and MM and C were able reduce leaching by around 30 – 40 %, as shown in figure 3. Soil+sorbent-water partitioning coefficients $K_{D\text{soil+sorbent}}$ values were calculated and they were up to 16 960 L/kg for AC and around 5-20 L/kg for MM and C.



Discussion

One of the most interesting results from these shaking tests was the very high leaching of PFOS in unamended soil samples. Soil washing involves the addition of large amounts of water to soil to rinse it and then treatment of the contaminated water. At the airport site, existing infrastructure and pump and treat water treatment systems mean that the feasibility of in-situ soil washing as a remediation strategy can be tested. At present in-situ soil washing is being field trialed at one of the six fire-fighting training platforms whereby large amounts of water are being added to the top of the soil in order to act as a "flush" and concentrations in the rinse water and the soil after washing are being measured. Preliminary results suggest that this method is very promising for the remediation of PFAS contaminated soil.

Likely residual concentrations that cannot be washed out of the soil will remain and these could then be stabilised with AC. Further testing of sorbent amendment will place an emphasis on testing the ability of the materials to stabilise higher PFOS concentrations, the effect of the presence of oil on the sorption capacity (since oil is often co-present at such sites), and the effect of increased and decreased sorbent doses. Such work is considered instrumental in order to suggest the most feasible site remediation options in collaboration with the Norwegian Airport Authority and the Norwegian Environment Agency.

FROM POINTSOURCES TO THE BALTIC SEA: FATE OF PERFLUOROALKYL ACIDS IN THE AQUATIC ENVIRONMENT WITH A FOCUS ON MASS BALANCE STUDIES

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Abstract

Perfluoroalkyl substances (PFASs) are man-made chemicals which are ubiquitously detected in the environment. During the last decade the focus on PFAS has increased in the Nordic countries. In order to increase the holistic understanding and the fate of PFAAs in the Baltic Sea, three studies were performed with emphasis on chemical trace analysis combined with mass balance modeling.

Introduction

Perfluoroalkyl substances (PFASs) are man-made chemicals. Their unique properties make them beneficial for a wide range of industrial and consumer product applications, such as in aqueous film forming foam (AFFF), durable water repellent clothing, hydraulic oils and food packaging materials. Perfluoroalkyl acids (PFAAs), a class of PFASs, are highly persistent in the environment, and long chain PFAAs are bioaccumulative and toxic (Giesy and Kannan 2002).

International regulation and voluntary actions by the industry have been implemented and led to a recent reduction of primary emissions of PFAAs to the environment. However, point sources such as AFFF training sites as well as diffuse sources continue to contaminate water bodies, soil and biota. Reducing environmental pollution with PFAAs has therefore become a regulatory priority. Designing successful measures to reduce the PFAA contamination requires an understanding of the sources, transport and fate of PFAAs in the environment.

The aim of this work was to increase the holistic understanding and the fate of PFAAs in aquatic systems. This was achieved by chemical trace analysis combined with mass balance modeling. The following topics were covered in three studies: **(I)** Dispersion and fate of PFAAs from waste water treatment plants (WWTPs) "pointing out" recirculation of PFAAs in the aquatic environment, **(II)** mass balance of PFAAs in the Baltic Sea and **(III)** transport and fate of PFAAs in two pristine boreal stream catchments.

Materials and Methods

In **Study (I)** three WWTPs in the cities Stockholm, Umeå and Bollebygd, (Sweden) were chosen to investigate the sources of PFAAs to and fate within the WWTPs see details in (Filipovic and Berger 2015). The three cities have varying population sizes and use different source water for tap water production, i.e., surface water, river infiltration and ground water. In order to investigate the sources of PFAAs to the WWTPs, tap water from the WWTP drainage area and influent samples were analyzed and PFAA concentrations compared. In order to understand the fate of PFAAs within the WWTPs, chemical mass balances were assembled including PFAAs in influents, sludge and effluents. All samples were collected during cold (below the freezing point) or dry sampling periods (without rain) to avoid a significant contribution of surface runoff to the WWTP influents. All sample extracts were analyzed using ultra performance liquid chromatography (UPLC) coupled to MS-MS.

In **Study (II)** mass balances of four PFAAs (PFHxA, PFOA, PFDA and PFOS) were assembled for the Baltic Sea, see details in (Filipovic et al 2013). The mass balances were based on the highest quality available literature data of PFAA concentrations in various media reported after 2006. Calculations were performed on a basin level. Due to the homogeneity of the PFAA concentrations in the different basins, a simple one-box model was finally applied for the Baltic Sea. Furthermore, mass balances of the four target PFAAs were also assembled for the river Oder catchment, in order to better understand the pathways of PFAAs to the rivers discharging into the Baltic Sea. To set bounds on the uncertainty, two estimates were calculated: a) High bound estimate (HBE), for which all of the data points reported as non-detected were set to the method detection limit (MDL), and b) low bound estimate (LBE), for which all of the data points below MDL were set to 0.

In **Study (III)** mass balances of ten PFAAs were assembled over a whole year for two pristine stream catchments within the Krycklan Catchment Study (KCS) approximately 60 km inland from the Baltic Sea in Northern Sweden. The two streams, hereafter referred to as stream 2 and stream 16 with their respective catchments C2 and C16, were chosen to represent different catchment sizes (C16 is the whole Krycklan catchment whereas C2 is a small sub-catchment) and hydrological functions see details in (Filipovic et al 2015). Atmospheric deposition was considered as input pathway and stream discharges as output pathway in the mass balance model.

Results

The results from **study (I)** shows the relative importance of environmental recirculation of PFAAs versus new releases from the techno sphere was investigated for PFAAs in WWTP influents. PFAA mass balances over the WWTPs suggested that PFHxA and PFOA were formed from precursor compounds within the Bromma, Stockholm WWTP is illustrated in 1 A, for more details (Bollbygd and Umeå) see (Filipovic and Berger 2015). It was shown that tap water can be an important source of PFAAs to WWTPs in areas with elevated environmental levels see Figure 1B. This needs to be taken into account when calculating emissions via WWTP effluents.

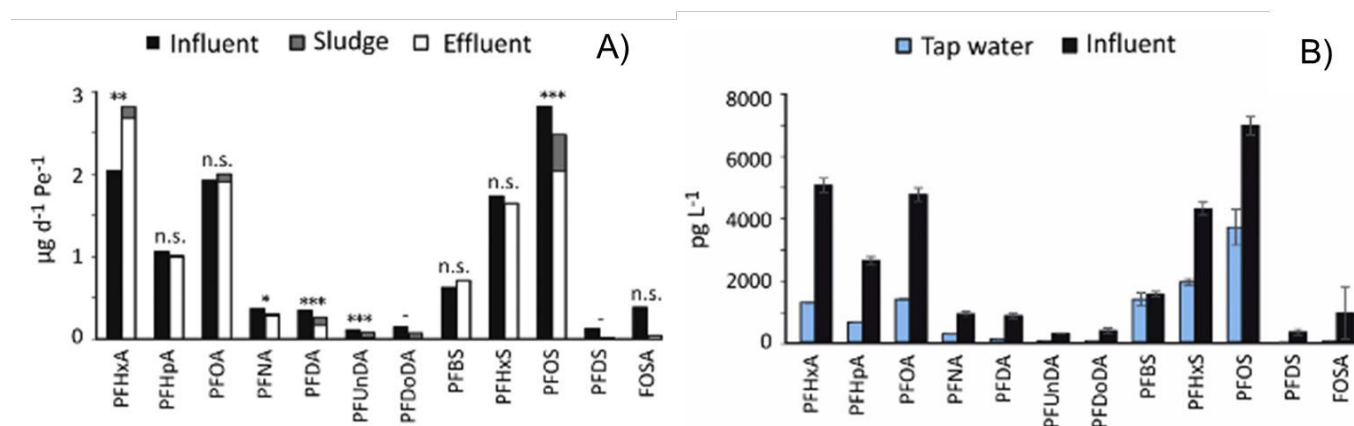


Figure 1. Population normalized daily chemical mass flows in influents, effluents and sludge for the different PFAAs in (A) Bromma WWTP. Statistical differences between the mass flows in influents and effluents are indicated as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s. not significant ($p > 0.05$) and a dash (–) means that no test was performed due to more than 50% of the observations $< \text{MDL}$ in influent and/or effluent. (B) Comparison of average PFAA concentrations in WWTP influents and the respective tap water in Bromma/Stockholm.

The results from **study (II)** show that the assembled PFAA mass balances for the Baltic Sea showed that river inflow and atmospheric deposition were the dominant input pathways, while waste water

treatment plant (WWTP) effluents discharging directly into the Baltic Sea made a minor contribution see Table 1. The inputs of PFAAs were estimated to be higher than the outputs, suggesting a current increase of the PFAA inventory in the Baltic Sea for more details see (Filipovic et al 2013).

Table 1. Summary of the PFAA mass balances for the Baltic Sea. The ranges are delineated by the low bound estimates (LBE) and high bound estimates (HBE).

Input [kg/yr]	PFHxA	PFOA	PFDA	PFOS
Riverine discharges	16-426	401-641	54.4-311	876-924
Atmospheric deposition	60.2-62.9	365-367	141-144	239
WWTP discharges	6.84	10.6	0.72-0.99	12.6
North Sea inflow	80.8-85.5	66.5-69.4	0.00-6.18	0.00-14.3
Sum	164-582	843-1090	195-462	1130-1190
Output [kg/yr]	PFHxA	PFOA	PFDA	PFOS
Sediment burial	2.18	14.9	5.53-23.3	17.7
Danish Straits outflow	155	370	16.5-47.5	177
Transformation	0.0940	0.210	0.00770-0.292	0.0983
Sum	157	385	22.0-70.8	195
Inventory [kg]	PFHxA	PFOA	PFDA	PFOS
Baltic Sea water	3080	7270	260-1030	3460
Sediment	125	827	314-1250	986
Sum	3200	8100	574-2280	4450

The results from **study (III)** show the mass balance of PFAAs in two remote stream catchments (Filipovic et al 2015), they revealed that inputs dominated over outputs for both catchments, indicating that a considerable portion of the PFAAs deposited from the atmosphere is retained in soil or in deep ground water and may be released to surface and marine water environments in the future see Figure 2 A and Figure 2 B.

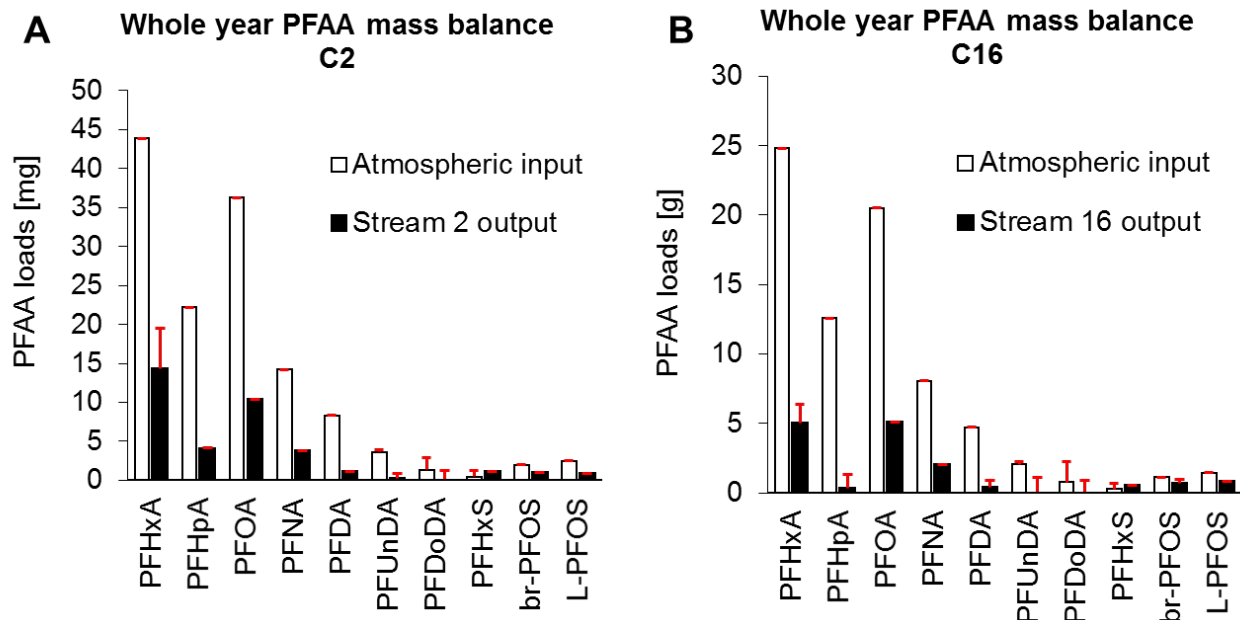


Figure 2. Total PFAA atmospheric inputs (white bars) and stream discharges (black bars) over the whole year are compared for A) C2 and B) C16. The LBE values are shown with solid bars and the HBE values with error bars.

In **study (III)** it was observed that PFHxA and PFOA were higher in atmospheric deposition collected during summer (rain) compared to winter (snow) see (Filipovic et al 2015). The increases in PFHxA and PFOA concentrations in rain, is suggested to be due to an increase of oxidation of precursor compounds during summer (longer days) compared to winter (short days). The amount of free radicals in atmosphere is correlated with the amount of radiation in this case sun-hours.

Discussion

The extraordinary persistency together with the widespread distribution and high mobility of especially short chain PFAAs lead to an environmental recirculation of PFAAs. This phenomenon is explored in detail in **study (I)** for WWTPs (Filipovic and Berger 2015). But also in the context of the presence of PFAAs in atmospheric deposition samples in **study (III)** the question of environmental recirculation as a potential pathway for PFAAs to the atmosphere was discussed. Environmental recirculation needs to be investigated and understood better in order not to overestimate current (new) emissions of PFAAs.

PFAA precursor compounds have not been investigated within these three studies. Nevertheless, indirect evidence in both **study (I) and (III)** suggested that precursor degradation is an important contributor to current PFHxA and PFOA emissions to the environment (Filipovic et al 2015). The relative importance of a multitude of precursors for environmental levels of PFAAs is a current research topic, but still far from being well understood.

A major conclusion from **study (II)** is that atmospheric deposition is likely the primary pathway for PFAAs to the European Nordic environment, whereas emissions via WWTPs play a minor role. However, this may look different in other parts of the world. Furthermore, it remains to be investigated whether or not PFAA levels measured in atmospheric deposition are influenced by environmental recirculation. From our current understanding discussed in **study (II)** we can expect that the levels of long chain PFAAs in the Baltic Sea are increasing. This is in line with the conclusion discussed above that a considerable fraction of historic emissions of long chain PFAAs is assumed to be stored in soil and slowly leaking into ground water and surface water (**study II and III**). Hence, the concentration peak in the aquatic environment may well lie ahead of us for several PFAAs.

In 2011 the European Commission proposed a European quality standard (EQS) for PFOS in marine waters. According to the EQS, PFOS levels in marine waters should not exceed 0.13 ng L⁻¹. Current PFOS levels in the Baltic Sea clearly exceed the EQS and are expected to increase for an unknown period of time in the future (**study II**). This poses a challenge for industry, scientists, engineers and regulators alike.

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Lessons Learned and Challenges Encountered after Characterizing >100 Poly-and Perfluoroalkyl Substances Impacted Sites

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Background

Poly-and Perfluoroalkyl Substances (PFASs), such as perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), are a class of compounds widely used in diverse applications, such as carpet protection, surfactants, and shampoos. In particular, PFAS-based surfactants have been used in aqueous film-forming foams (AFFF) that have been routinely used in both civilian and military fire-fighting. Historically, effluents from AFFF fire-fighting activities were neither impounded nor pre-treated prior to discharge to water treatment systems or to the environment. Widespread environmental presence of PFASs has been identified. PFASs are persistent, bioaccumulative, toxic, and are not readily degradable by conventional biological and abiotic treatment technologies. Thus PFASs have drawn increasing public and regulatory concerns including being listed on Annex B of the Stockholm Convention on Persistent Organic Pollutants (POPs) and US EPA's Unregulated Contaminant Monitoring Rule-3 (UCMR-3) list. The UCMR-3 listing requires that large Public Water Systems sample and analyze six PFASs and has already revealed PFAS impacts to some of these systems. These impacts and other PFAS related regulatory initiatives around the globe have resulted in a dramatic increase in the number of sites characterized for PFASs.

Aim

This presentation will highlight lessons learned and common challenges encountered from characterizing >100 PFAS impacted sites. This presentation also highlights a number of unique concerns and protocols that must be followed due to the characteristics of PFASs and significant potential for sample contamination.

Conclusion

PFASs represent a number of unique challenges and are unlike any prior class of compounds the environmental industry has had to deal with in the past. The high solubility of PFASs and associated resulting large dilute plumes, low laboratory detection limits and screening or cleanup criteria, presence of PFASs in many of the products routinely used during groundwater sampling, and potential for non-point sources of PFASs (e.g. dust) all create the need for unprecedented care to ensure an accurate Conceptual Site Model is developed on PFAS impacted sites and that associated risks are properly evaluated. This presentation will provide valuable insight into the extraordinary care and methods that should be followed when characterizing a PFAS impacted site and allow others to benefit from this significant data set/experience.

Mapping of PFAS contamination beyond firefighting sites

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Background

Perfluorinated chemicals (PFAS) are a group of synthetic hazardous substances broadly applied in fire-fighting foam and the impregnation of paper, textiles and carpets. Several studies have confirmed the presence of soil and groundwater contamination at firefighting sites. However, little is known about the connection of PFAS uses and their effect on soil and groundwater contamination.

Moreover, PFAS pose an analytical challenge, as there exist around 1000 compounds, but currently analytical methods are available for only 40 compounds. Often the used PFAS compounds are precursors whilst analytical programs only in degradation products such as PFOS and PFOA

Aim

The aim of this project is to perform a comprehensive mapping of all industries in Denmark that use/have used PFAS and to evaluate the potential for soil and groundwater contamination at those. To the extent possible specific PFAS compounds will be linked to specific activities. On this basis the design of the analytical program of future site investigations can better be targeted compounds that are specific to that activity.

Conclusion

The project was initiated in January 2016 and will be completed by June 2016. Previous projects by the Danish EPA have reported different PFAS applications. The presentation will include information from the Danish Product Register on the use of PFAS products from at specific industry types. It will cover the period from 1983 until 2016.

Moreover, the use of PFAS at different industries will be elucidated through interviews with industry personnel and a review of international literature.

The project will result in a recommendation of industries and activities where soil and groundwater investigations should be performed.

Session C

Circular Economy - Sustainable Remediation

Keynote Speaker: Approaches for assessing sustainable remediation – *Gitte Lemming Søndergaard, Senior Researcher, DTU Environment, Technical University of Denmark (DTU), Denmark*

INSURE a cross border project in the central baltic region about sustainable remediation – *Jenny Hultgren and Magnus Kviele, County Administrative Board of Östergötland, Sweden*

Beneficial re-use of contaminated harbor sediments – massive Scale application in the port of Klaipeda, Lithuania – *Markus Wilke, Huesker Synthetic , Germany*

APPROACHES FOR ASSESSING SUSTAINABLE REMEDIATION

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Abstract

Sustainable remediation seeks to reduce direct contaminant point source impacts on the environment, while minimizing the indirect cost of remediation to the environment, society and economy. This paper presents an overview of available approaches for assessing the sustainability of alternative remediation strategies for a contaminated site. Most approaches use multi-criteria assessment methods (MCA) to structure a decision support process. Different combinations of environmental, social and economic criteria are employed, and are assessed either in qualitative or quantitative forms with various tools such as life cycle assessment and cost benefit analysis. Stakeholder involvement, which is a key component of sustainable remediation, is conducted in various ways. Some approaches involve stakeholders directly in the evaluation or weighting of criteria, whereas other approaches only indirectly consider stakeholder preferences. MCA methods are very useful when comparing remediation alternatives, since they allow for a joint assessment of many types of indicators; however the available tools and methods differ substantially, for instance in their selection of indicators, approaches to stakeholder involvement and uncertainty analysis.

Introduction

It has been estimated that there are approximately 2.5 million potentially contaminated sites in Europe. Of these, approximately 340,000 sites are estimated to be contaminated to a degree that may require remediation (Van Liedekerke et al. 2014). Until recently, remediation was considered to be inherently green or sustainable since it removes a contaminant problem. However, it is now broadly recognized that while remediation is intended to address a local environmental threat, it may cause other local, regional and global impacts on the environment, society and economy. Over the last decade, the broader assessment of these criteria is occurring in a movement toward 'sustainable remediation'.

The Brundtland Report by the World Commission on Environment and Development (UN 1987) defined sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Harbottle et al. (2008) presented a framework for assessing sustainability of contaminated land remediation focusing only on the technical and environmental sustainability of the remediation technology. Subsequently a number of different definitions of sustainable remediation have been proposed. A common feature is that they employ a "triple bottom line approach" addressing the three pillars of sustainability: environment, society and economy (SURF 2009, SuRF-UK 2010, Sparrevik et al. 2011, Sparrevik et al. 2012, Søndergaard et al. 2014, Rosén et al. 2015) (Figure 1). Sustainable remediation eliminates or controls contaminant risks while minimizing negative environmental, social and economic impacts. A well balanced decision support processes must therefore address all three aspects.

While the assessment of environmental impacts of remediation systems for contaminated sites using life cycle assessment (LCA) is a well-studied field (Lemming et al. 2010a, 2010b, 2012), the assessment of sustainability is a relatively new discipline in the remediation sector. Methodologies are still in their infancy, there are few documented case studies, and quantitative assessments are especially lacking. An ISO guidance document for the assessment of sustainable remediation is expected to be published in late 2016 with the aim of describing the main concepts and creating common terminology (Nathanail 2016).

In this paper we present and compare the available tools and methods for assessing the sustainability of remedial solutions and discuss some of the key issues and future challenges. The aim of a sustainability assessment is to compare the sustainability of two or more remedial solutions for a contaminated site. A sustainability assessment does not provide an absolute measure of whether remediation of a specific site is sustainable. Instead it provides a relative measure which can be used to select the most sustainable solution from amongst a number of defined remedial scenarios.

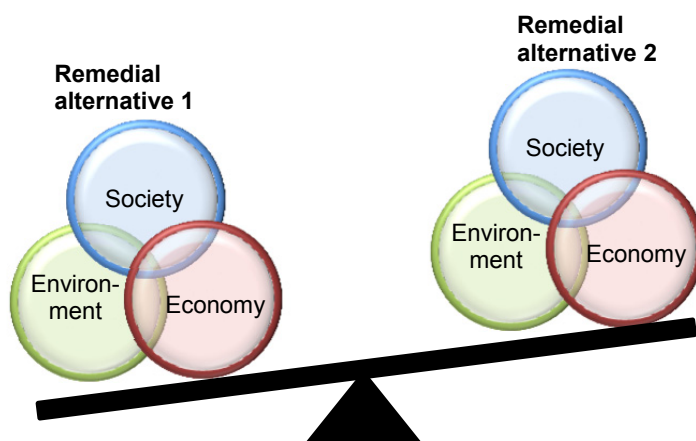


Figure 1. The triple bottom line approach for comparing the sustainability of remediation alternatives

Approaches and indicators for assessing sustainable remediation

An overview of approaches for assessing the sustainability of remedial alternatives is provided in Table 1. The overview mainly includes approaches that consider all three dimensions of sustainability. For completeness, however, earlier methodologies such as the REC tool (Beinat et al. 1997) and the Harbottle et al. (2008) framework are included even though they lack one or more dimensions. The REC tool was intended to be a decision support system for comparing remediation methods and is not a sustainability assessment tool. The Harbottle et al. (2008) framework is a multi-criteria assessment (MCA) approach for assessing the technical and environmental sustainability of a remediation system with less consideration of social and economic impacts. The MCA approach has subsequently been used in a number of sustainability assessment tools because of its ability to address many criteria at different scales and integrate qualitative and quantitative assessments.

Multi-criteria assessment approaches range from simple qualitative matrix-based scoring systems to semi-quantitative and fully quantitative methods. All of the studies shown in Table 1 (except Sparrevik et al. 2012) use the *linear additive model* which is a type of MCA method based on multi-attribute value theory (MAVT) or multi-attribute utility theory (MAUT). In MAVT/MAUT criteria scores are transformed into normalized values (e.g. on a scale from 0 to 1) and the overall value, v , of an alternative x , is calculated based on the weighted sum of the normalized criteria values as shown in Equation 1:

$$v(x) = \sum_{i=1}^n w_i v_i(x_i) \quad \text{Equation 1}$$

where $v_i(x_i)$ is the normalized value of criteria i , n is the total number of criteria and the weights w_i reflect the relative importance of the criteria, with the sum of the weights being one. The method is *compensatory*, meaning that criteria with high scores can compensate for other criteria with low scores. Sparrevik et al. (2012) employs *outranking*, a different type of multi-criteria assessment method where a comparative assessment of alternatives is conducted using the PROMETHEE II algorithm which ranks the alternatives without normalization of criteria values. Two of the studies in

Table 1 (Sparrevik et al. 2012 and Rosén et al. 2015) address uncertainty of the assessment using Monte Carlo simulations.

Table 1. Comparison of approaches for assessing sustainable remediation. LCA: Life cycle assessment. ^aUsing a linear additive model is a possibility, but not a requirement. ^bOnly for the remediation cost

Reference	MCA type	No. of indicators	Assessment type			Other main criteria	Weigh-ting	Stochas-tic/uncer-tainty
			Environmental	Social	Economic			
REC (Beinat et al. 1997)	Linear additive ^a	12	Quantitative (life cycle thinking)	-	Quantitative (costs)	Risk reduction	x ^a	(-) ^b
Harbottle et al. (2008)	Linear additive	17	Semi-quantitative; quantitative (LCA)	Semi-quantitative	-	-	x	-
Sparrevik et al. (2011)	Linear additive	9	Quantitative (LCA)	Semi-quantitative	Quantitative (costs)	-	x	-
Sparrevik et al. (2012)	Outranking	4	Quantitative (LCA)	Quantitative	Quantitative (socio-economic benefit)	-	x	x
SuRF-UK (2013a) Case study 2	Linear additive	16	Semi-quantitative; quantitative (CO ₂)	Semi-quantitative	Semi-quantitative; quantitative (costs)	Effectiveness and practical implementation	-	-
SuRF-UK (2013b) Case study 3	Linear additive	8	Qualitative	Qualitative	Semi-quantitative; quantitative (costs and selected benefits)	-	x	-
Søndergaard et al. (2014)	Linear additive	15	Quantitative (LCA); semi-quantitative (local soil impact)	Semi-quantitative	Quantitative (costs)	Effectiveness and time	x	-
Rosén et al. (2015)	Linear additive and non-compensatory	22	Semi-quantitative	Semi-quantitative	Quantitative (CBA)	-	x	x

For guidance purposes, SuRF-UK (2011) has developed a set of 15 environmental, economic and social indicator categories (see Table 2). Specific tools for assessing the impacts have not been specified by SuRF-UK. The total number of indicators employed in each of the 9 approaches in Table 1 varies between 4 and 22. Many of the approaches use LCA as a tool to assess impacts in the environmental domain, however SuRF-UK (2013a) uses only a simplified carbon footprint calculation. SuRF-UK (2013b) and Rosén et al. (2015) do not apply LCA. Environmental and economic impacts are often quantitatively assessed, but because of their nature, social impacts are most often assessed semi-quantitatively or qualitatively.

Table 2. Indicator categories defined by SuRF-UK (2011)

Environmental	Economic	Social
- Air emissions	- Direct economic costs and benefits	- Human health and safety
- Soil and ground conditions	- Indirect economic costs and benefits	- Ethical end equity
- Groundwater and surface water	- Employment and employment capital	- Neighborhoods and locality
- Ecology	- Induced economic costs and benefits	- Communities and community involvement
- Natural resources and wastes	- Project lifespan and flexibility	- Uncertainty and evidence

Discussion

A multi-criteria approach has been widely used to assess the sustainability of remediation systems because it can integrate different types of qualitative and quantitative data. Furthermore its structured approach facilitates a broader assessment of indicators and provides a more balanced and transparent decision support than traditional approaches which focus mostly on risk reduction and cost. A MCA also has the advantage of not requiring all criteria to be monetized. Rosén et al. (2015) suggests that a fully quantitative CBA be conducted for the economic domain and Sparrevik et al. (2012) used a willingness to pay study to assess the socio-economic benefit of the remediation. The other approaches only quantify direct costs and other costs and benefits are then covered by qualitative assessments. The use of extensive CBAs for the economic domain requires

considerable resources and may be hampered by the difficulty of treating externalities consistently since their evaluation is often based on different primary sources and assumptions.

In the environmental domain, some sustainability assessment methods focus only on air emissions of selected substances such as CO₂. Assessments do not always take a life cycle view of environmental impacts meaning that only emissions related directly to the remediation are considered and not upstream and downstream processes (raw material extraction and production of goods, waste treatment). Sometimes only life cycle impacts of remediation technologies are considered while local impacts such as those on soil quality are ignored. Such simplifications may bias the assessment.

One difficulty of fully quantitative MCA is that it requires expensive data collection and careful data processing. Therefore, Bardos et al (2016), SuRF-UK 2013b and others advocate a tiered approach to ensure that sustainability assessments are not unnecessarily complex, and that there is a balance between the cost of the evaluation and the benefit of the remediation project.

When selecting sustainable solutions for contaminated site remediation, the involvement of stakeholders is critical in order to ensure solutions are well accepted by the community and have a lasting impact. Stakeholder involvement is tackled in various ways in the approaches presented in Table 1. Sparrevik et al. (2011) and Søndergaard et al. (2014) employ a stakeholder panel to derive the criteria weights applied in the linear additive model (Equation 1). Harbottle et al. (2008) and Rosén et al. (2015) included “stakeholder acceptability” or “local acceptance” as a criterion in the social domain. Sparrevik et al. (2012) used three sets of predefined criteria weights representing different decision profiles (cost effectiveness, cost benefit and value plural profiles). Stakeholders were not directly involved in the case studies provided by SuRF-UK (SuRF-UK 2013a,b).

Conclusion

This study has reviewed available methods for assessing and comparing the sustainability of contaminated site remediation alternatives. Recently a variety of methods have been developed which address all three pillars of sustainability: environment, economy and society. The methods all employ multi-criteria analysis because it allows the combined assessment of criteria which may be either quantitatively or qualitatively assessed. To date very few documented assessments of sustainable remediation have been published. Further work is needed to test the assessment approaches for real case studies so they can be refined and further developed, for example to improve methods for involvement of stakeholders and to address the uncertainty of results.

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INSURE – A CROSS BORDER PROJECT IN THE CENTRAL BALTIC REGION ABOUT SUSTAINABLE REMEDIATION

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Background

INSURE is a project funded by the Central Baltic Programme with seven partners from Finland, Latvia and Sweden that is running from September 2015 to August 2019. The project will work to decrease the impact of hazardous substances to the Baltic Sea from contaminated sites. Contaminated sites are very numerous in all countries participating in the project and there is a joint requirement for better knowledge about how to work with the problem in a more efficient and high quality way. The number of performed remediation needs to increase to obtain a healthier environment and improved water quality in the Baltic Sea.

Aim

INSURE will work to make the remediation of contaminated sites more frequent and sustainable. During the project five pilot areas will be investigated and tested for the function of sustainable remediation alternatives. INSURE will also work with management methods such as supervision to create a more efficient handling of contaminated sites and thereby an increased remediation rate. Technical tools for better prioritisation and visualisation such as GIS, models and databases will be developed within the project to support the work with contaminated sites.

Conclusion

INSURE is a project with partners from different authority levels, university and company that jointly work towards increasing the rate of remediation of contaminated and changing the remediation methods to become more sustainable and resource efficient. All partners have unique experience, competences and knowledge and by combining them we will find new and innovative solutions within the field of contaminated sites.

Beneficial re-use of contaminated harbour sediments – Massive scale application in the Port of Klaipeda, Lithuania

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Abstract

Geosynthetic dewatering tubes have originally been developed for the dewatering of sewage and various slurries. As geosynthetic dewatering tubes unite the functions of solid-liquid separation with geotextile containment, they are ideal where dewatering and encapsulation are required simultaneously. The mode of operation is located in between the passive storage by spoil disposal areas and the active dewatering by means of mechanical devices such as belt presses, centrifuges or chamber filter presses.

This paper is intended to give an overview about the geosynthetic dewatering tube system projected to be used as encapsulation of contaminated sediments and as base for a harbour extension area. By the example of the Port of Klaipeda project, the principal workflow from dredging via dewatering by geosynthetic tubes to the final usage will be theoretically and practically described.

Introduction

The Port of Klaipeda, which can be traced back to the year 1252, is today a multi-purpose deep-water port operating 24/7 with a port territory area of 538.7 ha, a water area of 877.2 ha, and a total area of open storage sites of 1,045,879 m². Based in Klaipeda are 14 large stevedoring, shipbuilding, and repair companies providing all maritime business and cargo-related services. In order to regain the full draught of the floating docks in the harbour, a sediment volume of approximately 200,000 m³ beneath the docks had to be removed. Due to the long history of ship maintenance operations, the deposited sediments have been heavily contaminated by the typical occurring pollutants, like TBT, heavy metals, etc. After evaluation of different excavation, dewatering, and disposal techniques, the Port of Klaipeda decided to apply the geosynthetic dewatering tube system, as this system allows for dewatering and simultaneous encapsulation of the dewatered material. Due to this, the re-use as fill for a designated harbour extension area became possible. The dredging and dewatering works were carried out from late summer 2013 until autumn 2015. Before the start of operations a Contaminated Soil Disposal Site had been constructed within the harbour area in order to accommodate the large geosynthetic dewatering and containment units.

Geosynthetic Dewatering Tubes

Dewatering tubes are large confectioned geosynthetic elements with an almost elliptical cross-sectional shape after filling. By use of high strength seams for connecting the special filter fabric sheets this tubular element is formed. The long geotextile containment elements can be designed with a dewatering and storage function.

Dewatering tubes are available with standard dimensions but can also be customized with adopted tube dimensions for specific project requirements. The standard dimensions vary from small tubes with 30 m³ storage volume up to 65 m long elements with a containment capacity of approximately 1,600 m³ per unit.

Normally dewatering tubes are furnished with flexible inlets, distributed along the longitudinal axis of the tube. The tube filling is undertaken through these flexible nozzle inlets with the processed slurry.

Dewatering tubes can be installed in a single layer or stacked with multiple layers to form a pyramidal type geometry (see Wilke et al 2015 for case study on stacked tubes) providing an increased storage capacity in combination with a smaller footprint.

Geosynthetic tube design

The correct geotextile dewatering tube design comprises of two main design aspects:

1. The determination of the required tensile strength of the geosynthetic tube filter fabric to provide the dimensional stability of the assembled geosynthetic element.
2. The selection based also on filter criteria allowing for sufficient water relief capacity by optimized fine particle retention.

The required tensile strength of the geotextile tube is estimated using the linear membrane theory and is directly related to the circumference and the maximum filling height (Leshchinsky et al. 1995). To simplify the calculation procedure and to add speed, computerized software including Geo-CoPs (Adama) and SOFTWIN (Palmerton) can be used for the estimation of the tensile strength in the tube fabric.

As an output, the occurring maximum characteristic tube action is generated. The software offers the possibility to apply different specific reduction factors to the calculated hoop stress in order to determine the required short-term ultimate wide width tensile strength of the tube fabric.

Bezuijen et al. (2013) introduced an “overall” strength-reduction material factor as a combination of safety and reduction factors covering all aspects which have to be considered for the tube design. This tube performance factor should be above or equal to 3.5 as a minimum. Preferable are higher values increasing tube safeness.

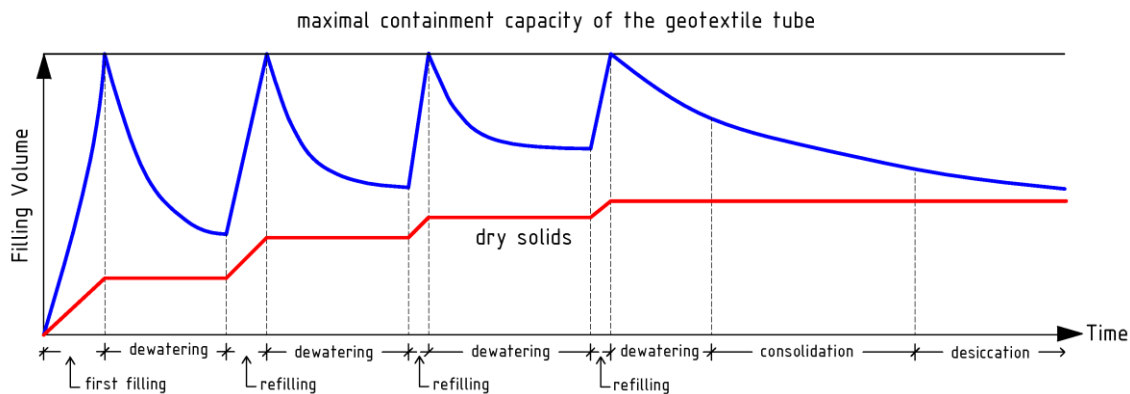
Special attention has to be paid to the fact that the required tensile design strength increases exponentially with increasing filling height. During the tube dimensioning, a proper optimization of the theoretical diameter, maximum filling height, storage capacity of the tube, and the required tensile design strength of the geotextile tube all have to be performed to ensure an optimal safe and stable design for the filling and dewatering operation.

Normally flocculation agents are added to the slurry stream prior to entering the dewatering tube. The purpose of the flocculation agents is to accelerate and enhance the dewatering process. By agglomerating the fine particles, the water release capacity and the soil retention ability of the fabric/tube are ameliorated. As this process is depending on the operation of the tubes, the slurry characteristics, the chosen flocculation aid, and the way of operating the dredger no principal design equation has been developed yet. In contrast to common filter design guidelines, which are not applicable to geosynthetic dewatering tubes, some performance indication standards have been developed: e.g. the ASTM D 7880: Standard test method for determining flow rate of water and suspended solids retention from a closed geosynthetic bag. A slight simplified variation of the ASTM 7701 is the “shopping-bag-test” which provides the same filtration ability insights as the American standard. Only by use of this index performance testing and sufficient experience in the field of dewatering tube application a secured estimation of the final real scale dewatering performance can be achieved.

Geosynthetic tube mode of operation

The dewatering by means of geosynthetic tubes comprises a cyclic process: The dewatering tube is initially filled to the given maximum initial design height, and the filling is stopped. Due to the particle retaining ability of the fabric, the solids deposit inside the tube and the water immediately is able to drain because of the fabric permeability. In the beginning, the process is mainly a suspension filtration. Directly after start of tube operation a natural filter cake develops on the inner side of the tube shell. This massively increases the degree of separation. The semi-static drainage of the sludge commences as soon as the filling process starts. After a varying operation time and following a degree

of dewatering the tube can be re-filled. During this cycle the water within the sludge is extracted, therefore the volume is reduced and the solids concentration of the residual dewatered material is increased. The principal process is repeated until the tube is completely filled. If the tube stays in place for an additional period of time, a subsequent consolidation and a further desiccation can occur. This process is schematically shown in Figure 1.



Schematic diagram of the dewatering sequence with geotextile tubes

Figure 1: Schematic dewatering cycle by use of geosynthetic tubes (adapted and modified from Lawson (2008) by Wilke (2015)).

Finally the tube is opened and the dewatered material with a solid state can be re-used or disposed. In the present case the tube integrity was kept for creating a permanent encapsulation element.

Port of Klaipeda tube operation adaption

The chosen mode of operation was a direct tube filing without a buffer or an intermediate storage. After extracting the sediment it was directly transferred by the floating dredge pipe along with intercalated polymer admixture into the tubes. For the operation of the floating docks with optimal draught a constant and levelled harbour bed platform below the floating docks is required. As the floating docks had to be kept in place there was a need for an optimized dredge barge with an adapted working mode. The solution consisted in the use of a modified auger head DOP pump with a reversible clap system mounted on a dredge barge. Having a theoretical dredging capacity of 1,300 m³/h the pump operated in the range of 300 to 800 m³/h at a dry solid content of 3 to 5 %.



Figure 2: Overview of the worksite in the Port of Klaipeda: Tube lay down and disposal area (black rectangular); floating docks to be cleared (1 & 2); dredge lines (blue).

By this approximately 200,000 m³ of sludge with an in-situ dried solid content around 34 % have been removed to bring the draught from 12 to 13 m down to 16 m. The dried solid content inside the tubes after dewatering was constantly tested above 40 %.

By installing the tubes in a two layer stack the storage capacity of the dewatering field was increased. All tubes exhibited a circumference of 28 m. The lower first layer tube length was set to 60 m whereas the top layer tubes consisted of 55 m length. Furthermore the tube lay down area was split in two cells with a maintenance road in between. The tube filling manifold system was installed along this maintenance road. The polymer was injected into the sludge stream at the entrance of the dewatering field via the main dredge discharge pipe. By an averaged cationic polymer consumption of around 1.7 kilogram of Polymer per ton dry solids (kg/tDS) a proper flocculation of the mud was achieved.

Initially the plan was to cover the tubes with soil after completion of this section. As the capacity of the dewatering field has not been used to the full extent this has not taken place yet. Currently the next section is tendered and the plan is to use the remaining capacities of the dewatering field for the upcoming work.

Discussion

The geotextile dewatering tube system has proven its applicability not only for dewatering but also for solid-liquid separation in combination with permanent containment of contaminated sediments. Due to the encapsulation effect of the geosynthetic shell formerly considered waste materials can be used for construction purposes. The Port of Klaipeda project is another successful implementation case study of geosynthetic dewatering tubes for remediation and beneficial re-use of contaminated harbor sediments.

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Notes

Lined area for notes, consisting of horizontal dotted lines.

Session D

Remediation Technologies - PART I

Thermal experiences in Denmark - *Thomas Larsen, Orbicon, Denmark*

Thermal remediation of 5-CAT, DCB, TCE and VC using a combination of steam and conductive heating adjacent to a commercial railroad track - *Niels Ploug, Krüger, Denmark*

Pilot study of electrokinetically delivered thermally activated persulfate in clayey till - *Lærke Nedergaard, Capital Region, Denmark*

Long-term evaluation of micro-scale zvi and organic carbon reactivity in a permeable reactive barrier application (US) - *Josephine Molin, PeroxyC, USA*

THERMAL EXPERIENCES IN DENMARK

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Background

The Danish maximum contaminant level for chlorinated solvents in ground and drinking water is 1ppb or less indicating that very effective means for the remediation are necessary at the solvent contaminated sites. Most of the source zone remediation is done by excavation and off site treatment, but in some cases in-situ methods such as thermal remediation technologies has been shown more feasible and therefor chosen as a remedy strategy.

The three most commonly used techniques for thermal remediation have been direct steam injection (SI), thermal conductive heating (TCH) and electrical resistance heating (ERH). Radiofrequency heating (RFH) has been applied at a pilot scale level too. In general, the remediation has been performed in order to reduce mass impact and risk for aquifers used for drinking water supply.

Until now approximately 15 full scale or experimental clean up using thermal techniques have been carried out in Denmark.

Aim

The aim of the talk is to convey some of the experiences obtained in connection with the different thermal treatment techniques; i.e. what is to be expected on price, need for accessibility, removal efficiency and residual contamination after cleanup, different challenges during remediation, geotechnical aspects etc.

Conclusion

All three methods have shown strong results with respect to removal rates. SI has been applied successfully in a number of more permeable large sites whereas TCH and ERH have been applied at more low permeable sites.

The size of the sites has varied from a few hundred m³ up to 50.000 m³ treated volume. Almost all the cases have had chlorinated solvents as the target removing from less than 100 kg up to around 3500 kg depending on the size of the site and the source strength. On most of the sites, some or the entire contaminant source zone has been below buildings and in many cases at greater depths (down to approximately 20 mbg).

Remediation efficiency has been highest for TCH with ERH and SI following close. The largest SI project was carried out in a very permeable geologic setting and the residual contamination both originating from the source zone and the downstream effect has been investigated for more than 5 years following the thermal treatment showing an initial reduction in mass flux from around 95 % to more than 99% within a couple of years after remediation.

Experiences from a relatively small number of ERH cases compared to TCH cases shows that the flexibility in the installation phase of TCH is lower than for ERH. On the contrary, with a well designed remediation plan ERH uses less energy to remediate the same volume of soil as ERH, although the residual content often is a little higher.

The most stringent levels of residual concentration of i.e. TCE has been observed using TCH with concentrations ranging from 0,1 mg/kg to below D.L. (0,01 mg TCE/kg).

Thermal remediation of 5-CAT, DCB, TCE and VC using a combination of steam and conductive heating adjacent to a commercial railroad track.

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Background

A former chemical dumpsite in Switzerland established on both sides of a commercial railroad track was excavated during 2013 – 2015. However at 1750 m² of the site the contaminants migrated to a depth where excavation was impossible due to risk of the railroad track.

Simplified, the geology is 5 - 6 meter of low permeable clay till underlain by a high permeable aquifer with a substantial groundwater flow of approximately 100 m/year. The target compounds were primarily Vinyl chloride, Trichloroethylene, 1,2 Dichlorobenzene, Chlorobenzene and 4-Chloro-2-Methylanilin (5-CAT) with boiling points ranging from -13 °C to 241 °C. This means that a treatment temperature of 100 °C will only provide partial treatment of the high boiling compounds.

The contamination is situated in a heterogeneous, low permeable unsaturated zone extending approximately 6 meters below ground and in a gravelly aquifer below the unsaturated zone. More than 98% of the mass is situated in the unsaturated part of the remediation zone. The groundwater aquifer has a substantial flow of approximately 100 m/year.

Aim

The challenge was to heat the high permeable aquifer and also ensure that the interface between the unsaturated zone and the saturated zone is heated thoroughly. To remediate the unsaturated zone, and at the same time provide remediation of the underlying groundwater, a combination of steam enhanced extraction in the saturated zone and Thermal Conduction in the unsaturated zone was implemented. The target treatment temperature for both unsaturated and saturated zone was 100 °C knowing that part of the unsaturated zone would reach higher temperatures due to the nature of thermal conduction.

Conclusion

The site has been remediated to the given criteria. The purpose of the talk is to show what cleanup levels was achievable with these higher boiling compounds using the approach. A comparison between design and actual key parameters such as energy consumption, temperature distribution etc. will be provided. Heating in the absolute vicinity of the railroad tracks were monitored and results of this survey will be discussed.

PILOT STUDY OF ELECTROKINETICALLY DELIVERED THERMALLY ACTIVATED PERSULFATE IN CLAYEY TILL

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Background

Successful source remediation of contamination (e.g. chlorinated solvents) in low permeable sediments such as clayey till is essential in the Capital Region of Denmark, because groundwater from the underlying limestone aquifer is used as drinking water. Currently, the most used source remediation technologies are excavation and thermal remediation, which are costly and energy consuming. Therefore, there is a need for in situ remediation technologies which are effective in low permeable media and more sustainable than excavation or thermal approaches. A full-scale study of the combined technology EK-BIO (migration of lactate and DHC under an applied electric field) has successfully been running at a field site in Skuldelev, Denmark since 2012. Electrokinetic migration overcomes the challenge of establishing the necessary contact between the reactants and contaminants in low permeability soils. The same concept is being used in a new technology demonstration, Electrokinetically Delivered Thermally Activated Persulfate (EK-TAP) which combines electrokinetic delivery of persulfate with heat activation through electrical resistance heating. If successful, EK-TAP can be an alternative remediation technology in low permeability soils for contaminants that cannot be degraded biologically.

Aim

After promising bench-scale studies, a pilot test of the EK-TAP technology is currently being performed at a test site in Ballerup, Denmark. The test site is contaminated with chlorinated solvents (primarily PCE and TCE) and the geology consists of partly saturated glacial clay tills overlying a Danien limestone formation. The pilot test is a single dipole test consisting of two electrode wells (anode and cathode) situated 3 meters apart. Two monitoring wells and four thermistor wells are installed in the test plot. The dipole test is divided into 3 operational stages; a pre-heating stage, an EK persulfate migration stage and a post-migration soil heating stage. In the EK persulfate migration stage, current is applied to the electrodes using a DC power supply and persulfate is amended to the cathode electrode well. During this stage migration of persulfate through the low permeable clayey till by direct current is assessed and a transport rate is determined. The assessment is based on data from monitoring of voltage gradients as well as pH, electrical conductivity, sulfate, and persulfate in pore water samples along with direct push profiling with HPT (Hydraulic Profiling Tool) and soil cores. After distribution of the persulfate throughout the test area, the post-migration soil heating stage is applied. At this stage an AC power is applied to the electrodes in order to heat the soil (via electrical resistance heating) to a temperature of minimum 35° C to activate the persulfate. Following the heating stage, soil cores are sampled from the test area and analyzed to assess the effectiveness of the combined remedy.

Conclusions

By January 2016 all three stages have been successfully completed and the post-test documentation sampling is currently on-going. Final conclusions and reporting will be carried out during the spring 2016. Experience with the technology and setup has been gained during all three stages of the pilot study and optimization of the design has been performed.

LONG-TERM EVALUATION OF MICRO-SCALE ZVI AND ORGANIC CARBON REACTIVITY IN A PERMEABLE REACTIVE BARRIER APPLICATION

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Abstract

Long-term effectiveness of *in situ* remediation applications is often based on the longevity of the amendments employed. In particular, in Permeable Reactive Barrier (PRB) applications and in cases with a continuing source, the longevity of the amendments employed will dictate the frequency of reapplication required. PRBs composed of granular Zero-Valent Iron (ZVI), have been demonstrated to last for over 10 years in the subsurface. Over the last decade, injectable amendments with more fine-grained ZVI has gained popularity as installation via direct push injection in many cases is more practical, cost-effective and less invasive. For example, EHC[®] is an integrated combination of controlled-release plant-derived organic carbon plus micro-scale ZVI particles, specifically formulated for application via direct injection. The first full-scale application of EHC into a flow-through reactive zone (injection PRB) was installed in April 2005 for interception of a 760 m long carbon tetrachloride (CT) groundwater plume. The purpose of this paper is to assess longterm performance of the PRB over time.

Materials and Methods

The Site is located in a small farming town in the midwest United States and is impacted with CT at concentrations of up to 2,700 ug/L. The CT plume extends approximately 760 m from a grain elevator where it discharged into a small creek (**Figure 1**). The CT source area is elusive, but impacts are likely the result of using CT as a fumigant in the grain silos on the site. There is a complex geologic history in the study area which resulted in a mix of interbedded sand, gravel, clay and silt. The groundwater table is encountered at approximately 7 m below ground surface (bgs); CT impacts extend down to a maximum of approximately 14 m bgs. The bedrock rises to an elevation of approximately 3 meters above the present day water table at the presumed source area, which complicates source area characterization and clean up. The CT is believed to have transported along the topography of the bedrock surface to the downgradient aquifer. Access restrictions due to residential properties further complicates source area clean-up immediately down-gradient from the suspected source area.

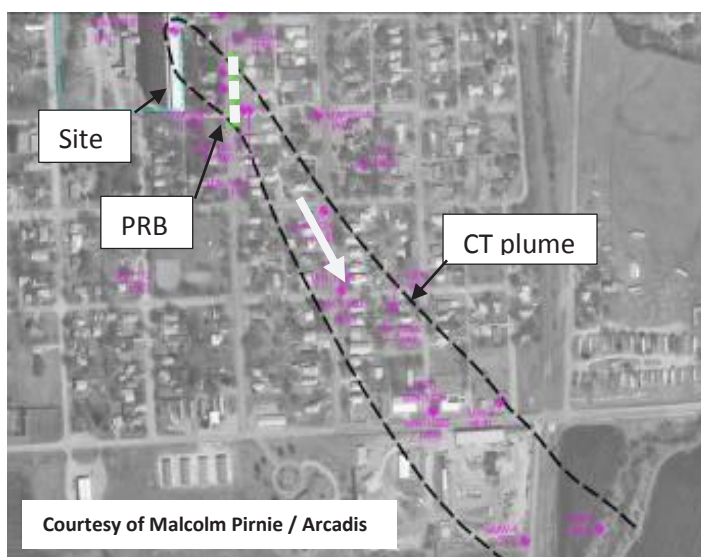


Figure 1: Direction of groundwater plume.

As an interim measure to prevent further plume migration, a PRB was installed across the plume in April 2005. The target goal for the PRB set forth in the Voluntary Clean-up Plan developed for the site is to maintain a removal efficiency of at least 95% reduction in CT compared to baseline concentrations at compliance points located 70 and 140 ft downgradient from the PRB.

In April 2005, a total of 22 tonnes of EHC was injected into an area measuring approximately 83 m long x 5 m wide x 3 m thick on average. The reactive zone was installed along the side of a road and extended across the plume. The EHC powder, composed of 40% micro-scale ZVI and 60% organic carbon derived from plants fibers, was mixed with water on site into slurry and injected using direct push technology in to a line of injection points spaced ca. 3 m apart. The EHC was emplaced at an average application rate of 1% by soil mass within the sand units. The installation was completed in 12 days (between March 30 and April 10, 2005).



Figure 2: Injection set-up with Chem Grout mixing unit and direct push probe.

Result

Following the installation of the PRB, performance monitoring was conducted on a quarterly bases for the first three years and then bi-annually since April 2008. **Figure 3** and **4** shows the concentrations of CT and daughter products measured in the two wells located immediately downgradient from the PRB, specified as compliance points for PRB replenishment. CT removal rates peaked 16 months after installation with >99 percent removal observed (21 m downgradient of the PRB (from a baseline of 1,000 ppb to <5 ppb). Two years after installation these rates decreased slightly to approximately 95-98 percent removal and stabilized there for 7 more years. However, since October 2014, 9.5 years after the PRB installation, breakthrough has started to be observed with the 95 percent guideline set forth in the Voluntary Clean-up Plan not being met for the first time. In the most recent sampling event available, conducted in October 2015, removal rates had dropped to 90% compared to baseline concentrations, not meeting the 95% removal requirement for the second time. Concentrations at the second compliance well, located 140 ft downgradient from PRB and at the edge of the plume, has remained non-detect (100% removal) for all analytes since August 2005.

Chloroform (CF) concentrations initially increased as a result of the CT degradation. However, by February 2007 CF had decreased below baseline and inflowing concentrations at the compliance well located 70 ft downgradient of the PRB. DCM and CM have remained below the detection limits in both the upgradient and downgradient wells since the May 2006 monitoring event.

Meanwhile, inflowing concentrations have fluctuated with a high of 2,700 ppb measured in February 2007 (**Figure 5**). The more recent years decline in inflowing concentrations may be explained by remedial efforts conducted at the source area, which was initiated in August 2011 (76 months after PRB installation) and expanded on in 2012 and 2013, where a shorter-lived liquid organic carbon donor (molasses plus water) was injected via fixed wells at the highest concentration area applied over a total of eight injection events. Two injection events with emulsified vegetable oil was also conducted at the source area in 2014 and 2015.

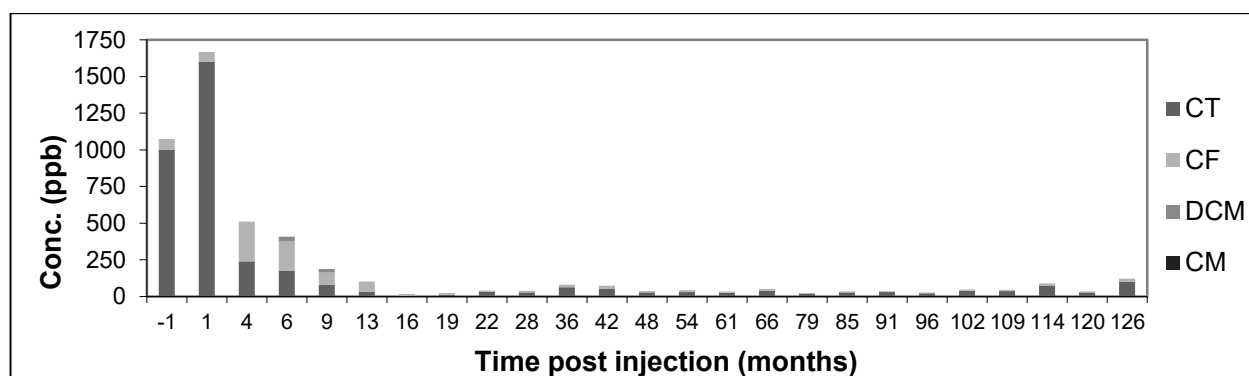


Figure 3: CT and degradation products measured in compliance well located 21 m downgradient from PRB at the center of the plume.

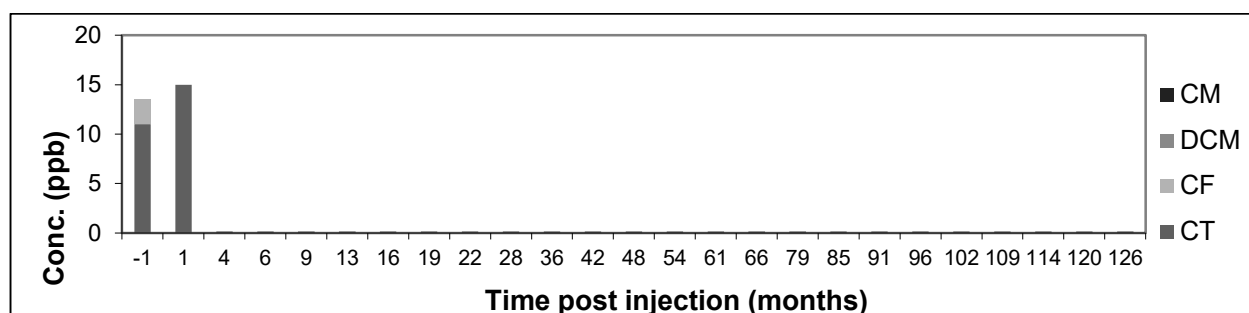


Figure 4: CT and degradation products measured in compliance well located 42 m downgradient from PRB at the edge of the plume.

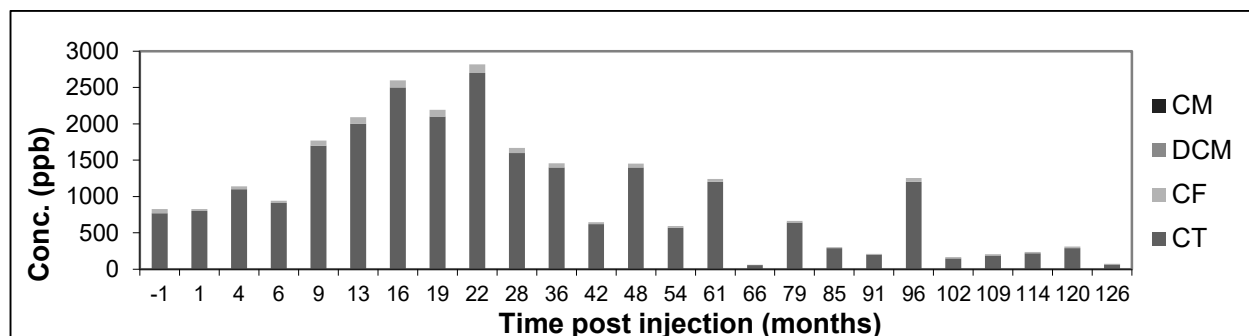


Figure 5: Inflowing concentrations measured in well located 26 m upgradient from PRB.

In February 2007, 22 months after the PRB installation, effects of the PRB started being observed as far as 183 m downgradient from the PRB. **Figure 6** shows the progression of the CT plume prior to and after installation of the EHC PRB. Groundwater levels measured over time did not indicate a change in groundwater direction following the installation of the PRB.

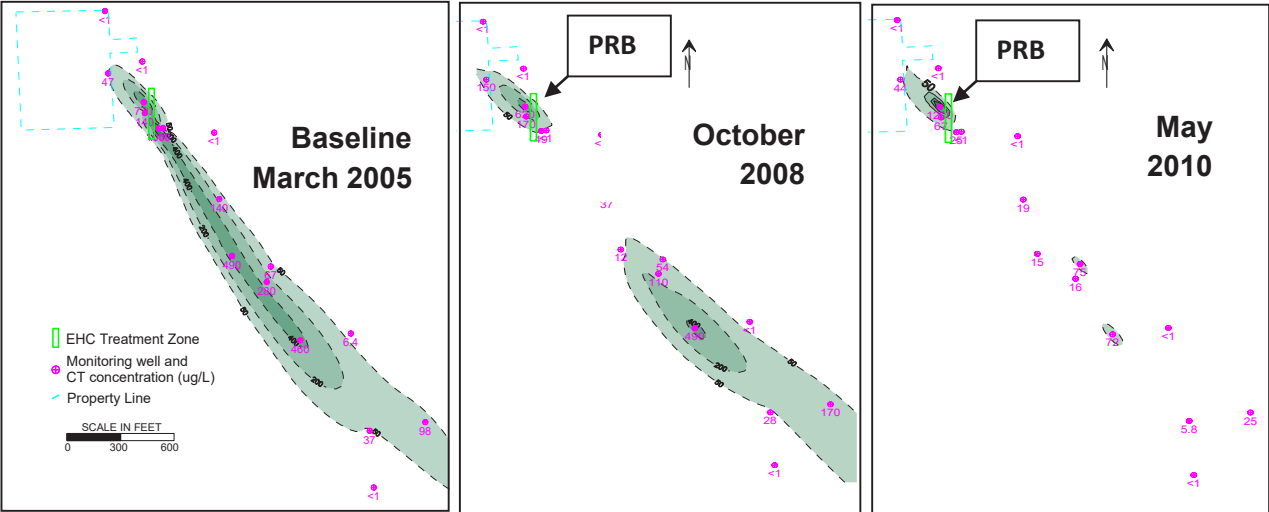


Figure 6: Impact of EHC PRB on extent of CT plume.

A significant increase in Total Organic Carbon (TOC) was measured immediately downgradient from the PRB initially. After about 2 years TOC levels returned closer to background levels, suggesting that the more readily degradable organic carbon component (cellulose) had been consumed. However, despite declining levels of organic carbon in groundwater, reducing conditions have been maintained for an extended period of time, likely by lower levels of DOC and from the hydrogen produced from ZVI corrosion.

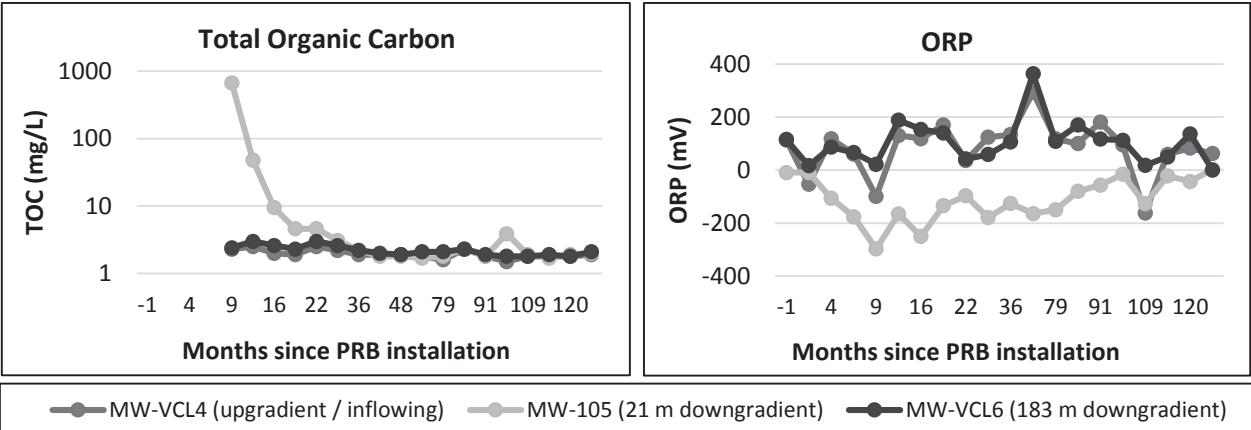


Figure 7: Effect on geochemistry downgradient from EHC PRB.

Discussion

A single application of EHC remained effective for 9.5 years before indications of breakthrough started to be observed. Since the installation of the PRB it has served to significantly reduce the size and concentration of the downgradient CT plume. Using an estimated linear groundwater flow velocity of 0.6 m/day and a porosity of 30%, the PRB has treated an estimated total of 140,000 m³ of groundwater during its life-time. The reactive zone constitutes a green solution (no energy requirements) and maintenance costs are limited to groundwater monitoring over the life of the PRB.

Session E

Methods for site studies PART I

Keynote Speaker: For Better Site Assessments, and Fate Studies in the Environment: The Benefit of Multielement Compound-Specific Isotope Analysis - *PhD Dr. Martin Elsner, Group Leader, Helmholtz Zentrum München, Institute of Groundwater Ecology, Germany*

Assessing sources and sinks of hexachlorocyclohexane (hch) isomers within a contaminated aquifer using compound-specific stable carbon isotope analysis (CSIA) - *Anko Fischer, Isodetect GmbH, Germany*

Soileffect: uptake and ahr-mediated effects of hydrophobic organic compounds into polyoxymethylene of different soil types - *Monika Lam, University of Örebro, Sweden*

Measurement techniques for detection of groundwater flows in bedrock and soil - *Jere Komulainen, Pöyry Finland Oy, Finland*

ASSESSING SOURCES AND SINKS OF HEXACHLOROCYCLOHEXANE (HCH) ISOMERS WITHIN A CONTAMINATED AQUIFER USING COMPOUND-SPECIFIC STABLE CARBON ISOTOPE ANALYSIS (CSIA)

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Abstract

The applicability of compound-specific stable carbon isotope analysis (CSIA) for assessing biodegradation of hexachlorocyclohexane (HCH) isomers was investigated in a contaminated aquifer at a former pesticide processing facility. A CSIA method was developed and tested for efficacy in determining carbon isotope ratios of HCH isomers in groundwater samples using gas chromatography - isotope ratio mass spectrometry (GC-IRMS). The carbon isotope ratios of HCHs confirmed contaminant source zones at former processing facilities, a storage depot and a waste dumpsite. The ¹³C-enrichment in HCHs provided evidence for biodegradation of HCHs especially downstream of the contaminant source zones. CSIA from monitoring campaigns in 2008, 2009 and 2010 revealed temporal trends in HCH biodegradation. Thus, the impact and progress of natural attenuation processes could be evaluated within the investigated aquifer. The Rayleigh-equation approach was applied for quantifying biodegradation of HCHs. Our study highlights the applicability of CSIA for the assessment of HCH biodegradation within contaminated aquifers.

Introduction

One of the most promising tools for monitoring *in situ* biodegradation of organic contaminants in aquifers is compound-specific stable carbon isotope analysis (CSIA) (US-EPA, 2008, Thullner *et al.*, 2012, Fischer *et al.*, 2016). Molecules with light carbon isotopes (¹²C) in the reactive position require less energy for bond cleavage and, thus, tend to be degraded faster than molecules containing a heavy carbon isotope (¹³C), resulting in an ¹³C-enrichment in the remaining stock of the pollutant. This process is called stable isotope fractionation and can be detected via changes in carbon isotope ratios (¹³C/¹²C, most commonly given as δ¹³C) of a pollutant toward more positive δ¹³C-values. Therefore, CSIA allows for the assessment of pollutant biodegradation based on the degree of carbon isotope fractionation observed at a contaminated field site.

In laboratory studies, significant changes in carbon isotope ratios have been observed for HCH biodegradation under both oxic and anoxic conditions. Anaerobic degradation exhibited higher carbon isotope fractionation of HCHs than aerobic degradation (Badea *et al.*, 2011; Badea *et al.*, 2009; Bashir *et al.*, 2013). However, limited knowledge exists on the applicability of CSIA for the evaluation of *in situ* biodegradation at HCH-contaminated field sites.

In our study, CSIA was applied for assessing biodegradation of HCHs in a contaminated aquifer. Besides hydrogeochemical parameters and pollutant concentrations, carbon isotope ratios (¹³C/¹²C) of HCHs were measured for three monitoring campaigns taking place in 2008, 2009 and 2010, in order to determine the progress and sustainability of HCH biodegradation. A comprehensive description of our study is given in (Bashir *et al.*, 2015).

Materials and Methods

The field site is located in the area of a former pesticide formulating plant that included both a formulation site and a packaging facility. As known from historical information, HCH was not produced on-site, but technical HCH was purchased from suppliers and γ-HCH was purified for use in pesticide formulation. HCH contamination of soil and groundwater were mainly caused by losses of HCH-containing raw

materials and products during purification, pesticide formulation and storage as well as irrigation and dumping of production-related wastes.

For the CSIA monitoring, 13 groundwater wells were sampled in 2008 and 15 wells in 2009 and 2010, respectively (Fig. 1). Wells 1 and 3 were established in 2009, in order to monitor the pollutant distribution in more detail within the groundwater upstream flow and the western fringe of the contaminant plume.

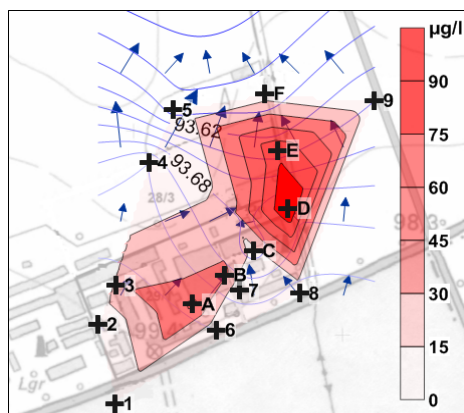


Fig. 1: Distribution of HCHs (sum of concentrations of HCH isomers [$\mu\text{g/L}$] in 2010) and groundwater flow direction (blue arrows) within the upper aquifer of the investigated field site. The main parts of the contaminant plume are: upstream flow (well 1), central flow (wells A to F), western fringe (wells 2-5), eastern fringe (wells 6-9).

For CSIA of HCHs, two 1L groundwater samples of each well were extracted three times with 30 mL dichloromethane in a separating funnel. The DCM extracts obtained from the two groundwater samples were combined and dried with anhydrous sodium sulfate. The combined DCM extracts were reduced to approximately 1 mL using a rotary evaporator. The extraction procedure did not result in significant changes in carbon isotope ratios of HCHs. CSIA of HCHs were performed by gas chromatography - isotope ratio mass spectrometry (GC-IRMS), using a system described elsewhere (Ivdrá *et al.*, 2014). The carbon isotope ratios ($^{13}\text{C}/^{12}\text{C}$) of HCHs were reported in the delta notation ($\delta^{13}\text{C}$) relative to the international standard Vienna Pee Dee Belemnite (VPDB) according to Eq. 1.

$$\delta^{13}\text{C}_{\text{sample}} = \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \quad (1)$$

R_{sample} and R_{standard} are the $^{13}\text{C}/^{12}\text{C}$ ratios of the sample and VPDB, respectively. The $\delta^{13}\text{C}$ -values were reported in per mil (‰).

Results

Since δ -HCH was the predominant HCH-isomer, most conclusions on sources and biodegradation of HCHs could be derived from $\delta^{13}\text{C}$ -values of δ -HCH in conjunction with its concentrations (Fig. 2).

The $\delta^{13}\text{C}$ -values of HCHs confirmed three distinct contaminant source zones at the field site, which were indicated by concentration data. Based on historical information, the source at well A can be considered to result from contamination at former processing facilities and the source at wells D and E from contamination at the former dump site of HCH wastes (Fig. 3). Moreover, a distinct γ -HCH source at well 3 seemed to originate from contamination at a former storage depot (Fig. 3). Since γ -HCH was the predominant HCH isomer, it can be concluded that it was stored in the vicinity of well 3 after purification of technical HCH.

The $\delta^{13}\text{C}$ -values of HCHs provided evidence of HCH biodegradation downstream of the HCH source zones at the former processing facilities and dump site, revealing that biodegradation contributed to the natural attenuation of HCHs within the investigated aquifer (Fig. 3). However, in some cases the decrease in concentration of HCHs was caused by physical processes. Since sorption and evaporation of HCHs can be neglected due to both the low organic matter content in the aquifer's matrix (0.014 %) and the low tendency of volatilization of HCHs from water (Sahsuvar *et al.*, 2003), dispersion, dilution and HCH recharge from the unsaturated zone into the groundwater are likely the most relevant physical processes influencing the concentration of HCHs within the aquifer.

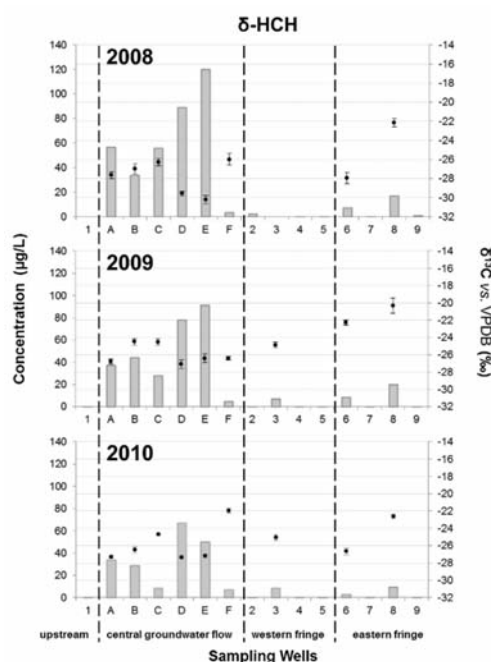


Fig. 2: Concentrations (bars) and $\delta^{13}\text{C}$ -values (dots) of δ -HCH for the monitoring campaigns in 2008, 2009 and 2010. Wells 1 and 3 were established in 2009, thus, concentration and isotope data are not available for the monitoring campaign in 2008. Uncertainty of concentration analysis is $< 10\%$ in all cases. Errors of $\delta^{13}\text{C}$ -values are indicated as error bars.

From 2008 to 2010, HCHs showed a decrease in concentrations concomitant with more positive $\delta^{13}\text{C}$ -values of HCHs, indicating that the contribution of biodegradation to natural attenuation of HCHs increased over time. At few wells, HCHs displayed an inconsistent relationship between changes in $\delta^{13}\text{C}$ -values of HCHs and changes in concentrations. In those cases, trends of concentrations of HCHs could provide information on the overall natural attenuation or recharge of HCHs but only limited indications for biodegradation. In addition, CSIA could more precisely reveal whether biodegradation contributed to natural attenuation of HCHs and, therefore, provided considerable information on the fate of pollutants at the field site.

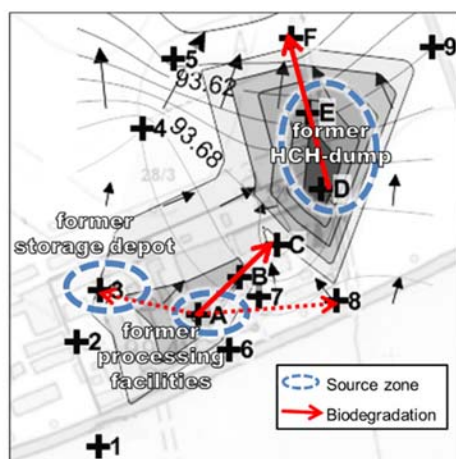


Fig. 3: Conceptual site model for sources and sinks of HCHs improved by the CSIA study. Dashed ellipses show pollutant source zones. Solid red arrows illustrate HCH biodegradation, whereas dotted red arrows show expected HCH biodegradation because direct flow paths between wells are ambiguous.

Using the Rayleigh-equation approach (Thullner *et al.*, 2012), calculations of the percentage of biodegradation (B [%]), distance- and time-dependent *in situ* first-order biodegradation rate constants (λ_s [1/m], λ_t [1/d]) for HCHs were carried out for flow paths within the main groundwater flow direction. Calculations yielded levels of HCH biodegradation ranging from 30 to 86 %. Moreover, time- and distance-dependent *in situ* first-order biodegradation rate constants were estimated with maximal values of $3 \times 10^{-3} \text{ d}^{-1}$ and $10 \times 10^{-3} \text{ m}^{-1}$ for α -HCH, $11 \times 10^{-3} \text{ d}^{-1}$ and $37 \times 10^{-3} \text{ m}^{-1}$ for β -HCH, and $6 \times 10^{-3} \text{ d}^{-1}$ and $19 \times 10^{-3} \text{ m}^{-1}$ for δ -HCH, respectively.

Discussion

Based on our study, we could highlight:

- the applicability of CSIA for the assessment of biodegradation and the source identification of HCHs within contaminated aquifers,
- the potential of CSIA for the quantification of HCH biodegradation,
- that time-resolved CSIA can reveal temporal variations in HCH biodegradation and provide information on the influences of various processes on natural attenuation.

Due to the intensive production of HCHs and their worldwide usage, there are a huge number of HCH-contaminated production, formulation and dump sites (Vijgen *et al.*, 2011). At these sites, time-resolved CSIA could be applied to identify trends in attenuation of HCH isomers and help to predict the evolution of contaminant plumes, as exemplified in our study. *In situ* biodegradation rate constants could be integral in modeling the current status and future development of contaminant plumes.

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SOILEFFECT: UPTAKE AND AHR-MEDIATED EFFECT OF HYDROPHOBIC ORGANIC COMPOUNDS INTO POLYOXYMETHYLENE OF DIFFERENT SOIL TYPES

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Abstract

SOILEFFECT is a three-year research project directed by the Örebro University in collaboration with Sweco, WSP, Golder and Eurofins, which focuses on enabling risk assessment based on the total toxicity and bioavailability rather than only chemical analysis. The aims of the present study are the identification of dioxins, PACs (PAHs, oxy-PAHs, azaarenes, and alkylated PAHs) and other potential contaminants present in industrial soils, and the development of a field sampling method for the available fraction of PACs and dioxins in soil using polyoxymethylene (POM) stripes with different thicknesses. POM stripes were exposed to soil for 4 weeks. Soil and POM stripes are analyzed by chemical analysis (GC/MS analysis) in combination with the H4IIE-luc- bioassay for AhR-mediated effects. POM stripes in the field seem to be a promising sampling method to measure the available fraction of dioxins and other hydrophobic toxicants in soil, but more studies need to be done to validate the method. Results from the bioassay analysis of the dioxin contaminated site showed that there is no difference between using different thickness of POM stripes (76 µm or 500 µm).

Introduction

SOILEFFECT is a three-year research project directed by the Örebro University in collaboration with Sweco, WSP, Golder and Eurofins, which focuses on enabling risk assessment based on the total toxicity and bioavailability rather than only chemical analysis. The overall goal of the project is to develop better methods for investigation of contaminated sites that lead to better and more extensive background information of the sites.

Contaminated sites contain a complex mixture of chemicals. Polycyclic aromatic hydrocarbons (PAHs) are common contaminants in industrial areas, especially at old gasworks sites, gas stations and former wood impregnation facilities, and occur as complex mixtures of thousands of PAHs, oxy-, nitro-, and alkyl-substituted PAHs and heterocyclic compounds (NSO-PACs) among others, collectively referred to as polycyclic aromatic compounds (PACs). The contaminant composition differ widely due to contamination sources and weathering processes in the environment. Studies have shown that traditional monitoring methodology of using chemical analysis of a small number of organic pollutants to determine the degree of contamination in environment matrices, like soil and sediment, usually overlooks potential contaminants present in the samples (Larsson et al., 2013; Andersson & Achten, 2015). In addition, exhaustive extraction methods are often used, which provide no information about the availability and ageing of the contaminants in the soil. Sampling of the available fraction of compounds in soil plays an important role for the estimation of the bioavailability and the assessment of risk to living organisms. The passive sampler polyoxymethylene (POM) is increasingly used to analyse the bioavailable fraction of organic compounds in soil and sediment and has shown promising properties for sorption of hydrophobic organic compound (HOCs), like PAHs and dioxins (Josefsson et al., 2015; Cornelissen et al., 2008).

The aim of the present study is to (A) identify dioxins, PACs (PAHs, oxy-PAHs, azaarenes, and alkylated PAHs) and other potential organic toxicants present in industrial soils, and (B) develop a field sampling method for the available fraction of PACs and dioxins in soil using POM stripes, and study the influence of different thickness size on the sorption of toxicants from soil to stripe. Soil and stripes are analyzed by chemical analysis (GC/MS analysis) in combination with a mechanism-specific cell-based bioassay

(H4IIE-luc). The H4IIE-luc assay detects all compounds that activate the Ah-receptor (AhR), like dioxins, PCBs and many PACs.

The goal with the study is to achieve a rapid, quantitatively and qualitatively correct sorption of all relevant and mobile toxicants from the soil, which enable a risk assessment/remedial action based on all available toxicants, and not only the effects of individual compounds.

Materials and Methods

Study sites

This present study was performed at two contaminated locations in Sweden. One of the sampling sites was a former wood impregnation industry using pentachlorophenol for wood treatment and thereby contaminated with dioxins. The other sampling site was an old gasworkstation, highly contaminated with PAHs.

Sampling

30 cm of soil was dug out in a rectangular shape and 20-40 POM stripes (≈12x5 cm) with a thickness of 76 or 500 μm were placed horizontally on the soil next to each other. The soil was put back on the POM. After 4 weeks, the POM stripes were collected, rinsed with millipore water, dried, covered in aluminum foil and stored at -20°C until extraction. In addition, a soil sample was collected close to every POM sample and was also stored at -20 °C until extraction.

Extraction

POM stripes were extracted 2 times for 3 hours with acetone: n-hexane (1:1) in an ultrasonic bath. POM-extracts were split for bioanalysis and chemical analysis. Soil samples of PAH-contaminated soil were extracted by pressurized liquid extraction (PLE) with in-cell clean up (deactivated silica) using n-hexane:DCM (9:1) as an extraction solvent. Soil samples of dioxin-contaminated soil were extracted and cleaned up on acid impregnated silica by our collaboration partner Eurofins

Analysis

Chemical Analysis (GC/HRMS) of 17 dioxins was carried out by Eurofins. Chemical Analysis (GC/LRMS) of 70 PACs including PAHs, alkylated PAHs, oxygenated PAHs, methylated dibenzothiophenes and azareenes is in progress at our laboratory. All POM and soil extracts were also analyzed in the H4IIE-bioreporter assay for AhR-mediated effects.

Evaluation

The bio-TEQs (EC25) were calculated from the concentration-response curve of the POM- or soil extracts by relating luciferase induction of the sample to luciferase induction of the reference compound TCDD. The following equation was used to calculate the bio-TEQ value:

$$\text{Bio-TEQ (pg/g)} = \frac{EC \text{ of TCDD}_x}{EC \text{ of extract}_x}$$

Chemically derived TEQs (chem-TEQs) were calculated using H4IIE-luc assay specific REPs and the quantifiable concentrations of the compounds. The total chem-TEQ was calculated by use of the following formula:

$$\text{Chem-TEQ} = \sum_{\text{substance}} \text{Concentration}_{\text{substance}} \times \text{REP}_{\text{substance}}$$

Results

Results from the chemical analysis of the dioxin contaminated samples showed that 15 of 17 dioxins were quantifiable in the soil (Tab.1). 1,2,3,4,6,7,8-HeptaCDD, OctaCDD, 1,2,3,4,6,7,8-HeptaCDF and OctaCDF were found in the highest concentrations.

Analysis of the POM stripes showed that most dioxins were below the limit of quantification. Only two compounds (1,2,3,4,6,7,8-HeptaCDD and OctaCDD) were quantifiable in the POM76 and 500 stripes.

Levels ranged from 19 to 310 pg/g POM for 1,2,3,4,6,7,8-HeptaCDD and 42 to 1100 pg/g POM for OctaCDD. Approximately 5 to 20 % of the concentrations measured in the soil were sorbed to the POM.

Tab. 1 Chemical Analysis of 17 dioxins in POM500 (N=10) or POM76 (N=10) and associated soil samples (N=20). Values are presented as mean values \pm stdev, < indicates values below LOQ.

	SOIL [pg/g soil]	POM500 [pg/g POM]	POM76 [pg/g POM]
2,3,7,8-TetraCDD	<0.51	<0,5	<0.59
1,2,3,7,8-PentaCDD	3.48 \pm 0.83	<1	<3.24
1,2,3,4,7,8-HexaCDD	5.13 \pm 1.34	<1	<5.72
1,2,3,6,7,8-HexaCDD	42.9 \pm 15.03	<1.45	<6.63
1,2,3,7,8,9-HexaCDD	10.37 \pm 1.86	<1.05	<3.01
1,2,3,4,6,7,8-HeptaCDD	543 \pm 198	33.90 \pm 25.23	155.30 \pm 69.52
OctaCDD	2590 \pm 860	103.20 \pm 82.82	499.00 \pm 286.10
2,3,7,8-TetraCDF	<1.1	<1	<1
1,2,3,7,8-PentaCDF	1.18 \pm 0.14	<1	<3.53
2,3,4,7,8-PentaCDF	1.46 \pm 0.73	<1	<1.02
1,2,3,4,7,8-HexaCDF	7.84 \pm 2.75	<1	<1.14
1,2,3,6,7,8-HexaCDF	7.15 \pm 1.55	<1	<2.55
1,2,3,7,8,9-HexaCDF	1.74 \pm 0.50	<1	<2.91
2,3,4,6,7,8-HexaCDF	3.77 \pm 1.17	<1	<1.55
1,2,3,4,6,7,8-HeptaCDF	358 \pm 413	<1	<1
1,2,3,4,7,8,9-HeptaCDF	20.40 \pm 6.54	<1	<1.52
OctaCDF	778 \pm 1370	<2	<17.01

Mass balance estimation, that is, correlation of predicted effects based on chemical analysis (chem-TEQs) to the observed effects in the bioassay (bio-TEQs), showed that the POM stripes had adsorbed a large proportion of biologically active AhR agonists that could not be explained by the chemical analysis. Bio-TEQ values of POM500 and POM76 were similar whereas chem-TEQ values of POM76 were 4-fold higher than chem-TEQ-values of POM500. The variation of the bio-TEQ of POM are greater than those from the chem-TEQ (Fig. 1). Bio-TEQs ranged from 29 to 197 pg/g for POM500 and 29 to 134 pg/g for POM76. Two samples of the POM500 did not have a detectable AhR-mediated effect and only five of 10 POM76 had a detectable AhR-mediated effect (Fig.2).

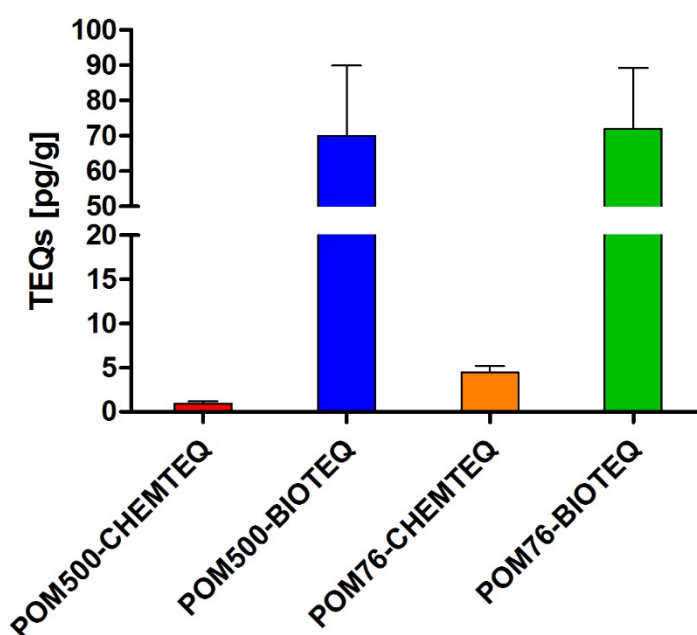


Fig. 1 TEQ-values of POM76 and POM500 of the dioxin- contaminated soil. Bars represent mean of TEQ-values and error bars the standard deviation.

Results from the analyzed gas work station samples indicate that there are a large portion of unknown potential toxicants in the gas work soil. Bio-TEQ values are much higher than the chem-TEQs. The soil samples contained oxy-PAHs, azaarenes alkylated PAHs, and dibenzothiophenes, sometimes in higher concentrations than parent PAHs.

Discussion

Using POM stripes as passive samplers in the field seems like a promising method for measure the available fraction of dioxins and other hydrophobic toxicants in soil, but more studies need to be done to validate the method. Results from the bioassay analysis of the dioxin contaminated site showed that there is no difference between using the different POM stripes (POM76 or POM500). POM 500 is more robust and easier to handle in the field. More studies are planned to evaluate the influence of different soil types, water content and sampling time on the sorption kinetics of toxicants from soil to stripes. Today, generic guideline values for PAHs in contaminated areas are usually based on chemical analysis of the 16 priority PAHs even though there are thousands of PAHs and similar substances in the soils. The results from the present study show that the gas work soil contain a lot of other polycyclic aromatic compounds not included in the 16 priority PAHs and also other toxicants not included in the chemical analysis. This means that most substances in contaminated areas are unknown and thereby the risk to humans and the environment. Use of bioassays, which measures the combined effect of concentration, toxicity and interactions of all toxicants with a common mechanism of action provides a more comprehensive picture of the pollution situation. Use of the passive sampling method in combination with bioassay analysis will take the bioavailability of all toxicants into account in a comprehensive manner, and thereby not overestimating the risk for substances with low bioavailability.

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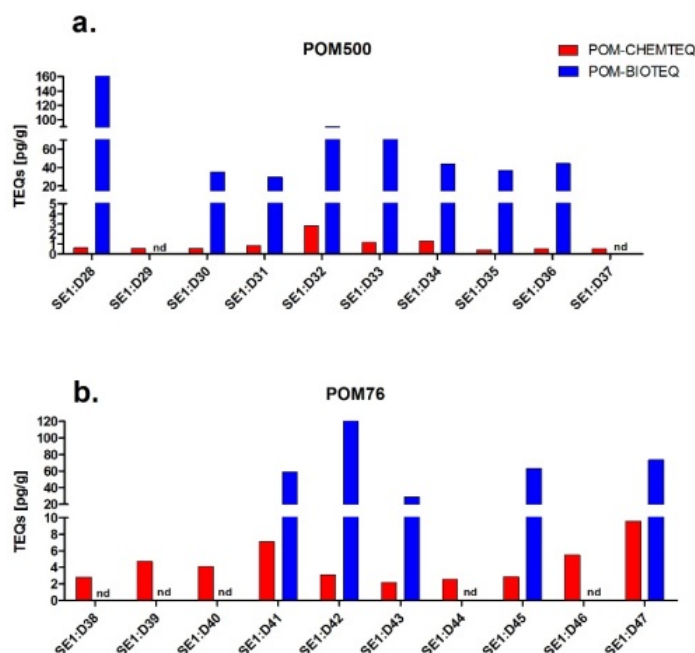


Fig. 2 TEQ-values of single POM with thickness of a. 500 µm and b. 76 µm . nd: not possible to determine a TEQ-value.

MEASUREMENT TECHNIQUES FOR DETECTION OF GROUNDWATER FLOWS IN BEDROCK AND SOIL

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Abstract

Groundwater flow in soil and bedrock can convey contaminants into large areas over a long time period. As the groundwater flows always have a direction the propagation of contaminants is not isotropic around the contaminant source. For the characterization and prediction of propagation of contaminants groundwater aquifers and water flowing structures need to be identified. Finding the aquifers in soil and bedrock can be difficult especially when the groundwater flows are very small.

Suitable measurement techniques for characterization of hydraulic properties (like hydraulic conductivity) of soil are slug tests and pumping tests. The actual groundwater flow (flow rate and direction) can be measured with the transverse flow measurements. In boreholes hydraulically conductive bedrock fractures can be measured in different pressure conditions to find out fracture transmissivities and flow across a borehole. All the above mentioned tests can be conducted as a single borehole measurement when surrounding conditions remain the same or with controlled interference. The controlled interference can be pumping of another groundwater observation tube or borehole in the same area where the measured tube or borehole is located. This gives more detailed information of the location of an aquifer.

Introduction

Posiva Flow Log (PFL) difference flow meter has been developed by Pöyry for Posiva for hydrogeological investigations for building of repository of high-level spent nuclear fuel. The development of the devices started 30 years ago and measurement have been conducted since early 90s. The device measures water flows in boreholes (Komulainen et al. 2016). The flow meter measures water flow down in a borehole and sends the measurement data up via digital data transmission.

The measurement technique is unique and there are no similar devices on the market. Spinner flow loggers measure the flow along a borehole but their resolution is not enough to detect small fracture flows. The closest equivalent to the PFL device are hydraulic testing units which measure hydraulic properties of fractures in bedrock by injecting water to fractures and evaluating pressure – flow relation. This kind of devices always require pressure from the ground level and therefore have high stability requirements for the transmission media down to the measurement device in a borehole. In PFL probe only connection to ground level is the four wire electrical connection using digital data transmission and is therefore immune to disturbances caused by long distance between measurement probe and data recording unit at ground level. The flow logging is also faster than hydraulic testing with water injection.

Materials and Methods

The PFL flow measurement probe is a 53 mm in diameter metal tube which contains measurement electronics and sensors. In addition to flow measurement temperature and electrical conductivity of water and absolute pressure is measured. The range of the flow sensor is 10 – 300 000 ml/h. Temperature range is 0 – 50 °C and electrical conductivity of water sensor range is 0.02 – 11 S/m. Pressure sensor range is 0 – 20 000 kPa which means full hydrostatic pressure at depth of 2000 m. In addition to the PFL flow meter the entire flow logging system consists measurement trailer containing winch for moving the measurement probe in a borehole and measurement computer that controls the measurement and record the measurement data. The winch contains 1500 m of cable so that is the maximum depth of a borehole that can be measured entirely.

The PFL measurement probe is the main component of the measurement devices and it is used with different kind of flow guides and accessories. Flow guides are used to channel the wanted water flow into the flow channel. A water sampling container can also be added to the PFL measurement probe that makes it possible to collect a water sample from the water flow that is measured (Ripatti et al. 2014).

In the basic construct of the flow guide the measurement section is isolated using rubber discs at upper and lower end of the measurement section (Figure 1). The water coming from fractures at the borehole section isolated with measurement section flows through the flow channel where the flow rate and direction of the flow is measured. The flow along the borehole goes through a bypass channel and therefore the measurement probe doesn't affect the pressure conditions in borehole. The measurement is conducted when the probe is at still and after one measurement at a location the probe is moved to a new location. Moving the probe doesn't affect the pressure conditions in a borehole as the water along a borehole goes through the bypass pipe. This makes it possible to keep the measurement time short as only very short stabilization time is needed after the probe has been moved to a new location. The stabilization time is needed to measure temperature of water at the measurement location.



Figure 1. Posiva Flow Log (PFL) difference flow meter

The measurement procedure is very straight forward, measure one point and move to another and so on. Length of the measurement section and length of measurement interval can be chosen based on the need. The shortest length of the measurement section is 0.5 m and shortest used measurement interval is 0.1 m. With these parameters locations of flowing fractures can be determined with the accuracy of ± 0.1 m. The length of the measurement section determines how well different fractures can be identified and measured if there are multiple fractures very close to each other. When the distance between fractures is longer than the length of the measurement section each fracture can be measured separately. When there are multiple fractures at the measurement section at the same time interpreting the fracture location and flow rate is more difficult. Sometimes it can be done and sometimes it cannot.

Finding the flowing fractures is not always enough but more information of hydraulic properties of the fractures is demanded. Hydraulic conductivity of individual fractures can be estimated based on the flow measurements if the measurements are conducted under different pressure conditions. Therefore measurements are usually conducted in natural conditions and under pumped conditions. In pumped conditions water level in a borehole is lowered which increases the flow rates towards the borehole.

Based on the two flow values in two different pressure conditions the flow rate in any pressure can be estimated. The measurement under pumped conditions also usually reveals more flowing fractures than the measurement in natural conditions.

Based on the measurements mentioned above the detected fractures can be measured with a transverse flow measurement device or water samples can be taken from the fractures (Komulainen et al. 2016). During the flow logging resistivity of the borehole wall is measured. This gives high resolution data of the borehole wall and it can be used to match the depth between different measurements. When transverse flow meter or water sampler is used it is easy to place the measurement device on the wanted fracture.

The water sampler is a water container and set of valves connected to the PFL probe. The measurement is similar compared to flow logging without water sampler but when water sampler is used the measurement device is stopped at wanted fracture and sampling of water is continued as long as it takes to reach stable flow and electrical conductivity of water values. Also the sampling time has to be long enough to fill the water container with the fracture water. After the container is full of fracture water the valves are closed and the water sample is lifted up from a borehole. The closed water container can be delivered to a laboratory maintaining the *in situ* water pressure.

The transverse flow meter is a PFL probe with a flow guide that divides a borehole section into two halves perpendicular to borehole. Also a ground water observation tubes can be measured if they have 2 m long or shorter perforated section where the water flows. The flow channel connects the two halves and if there is a transverse flow at the fracture it has to go through the flow channel. As the flow guide divides the borehole into two halves one measurement tells only which of the halves is the one where water comes and which one where the water goes.

The flow guide dividing borehole or ground water observation tube is an inflatable packer which expands at certain parts and forms the division. The water flowing along a borehole or tube is free to flow inside the flow guide therefore pressure difference over the measurement device cannot be formed. Also the water level in a borehole or a tube is measured during the flow measurement to monitor the conditions in a borehole or a tube. The temperature at measurement section is also measured as the flow measurement is based on the temperature measurement.

The flow guide can be rotated and measurements can be conducted in multiple orientations. The exact flow direction can be determined based on multiple measurements in different orientations. An example of measurement results with four different flow guide orientations are shown in Figure 2. In the Figure lines going through the center denote how the flow guide divides the borehole or ground water observation tube. In theoretical case flow pattern should be circular where highest value is to the direction of the flow and a zero flow should be found perpendicular to highest flow rate. The flow pattern is rarely ideal therefore at least four measurements should be conducted with different flow guide orientation.

The measurement time with one flow guide orientation depends on flow rate and how fast the flow rate stabilizes. Especially if flow rate is very small rotating the flow guide might affect the flow and flow stabilization might take hours. Therefore entire measurement time depends on flow stabilization but most likely one fracture in a borehole or one ground water observation tube can be measured in one day.

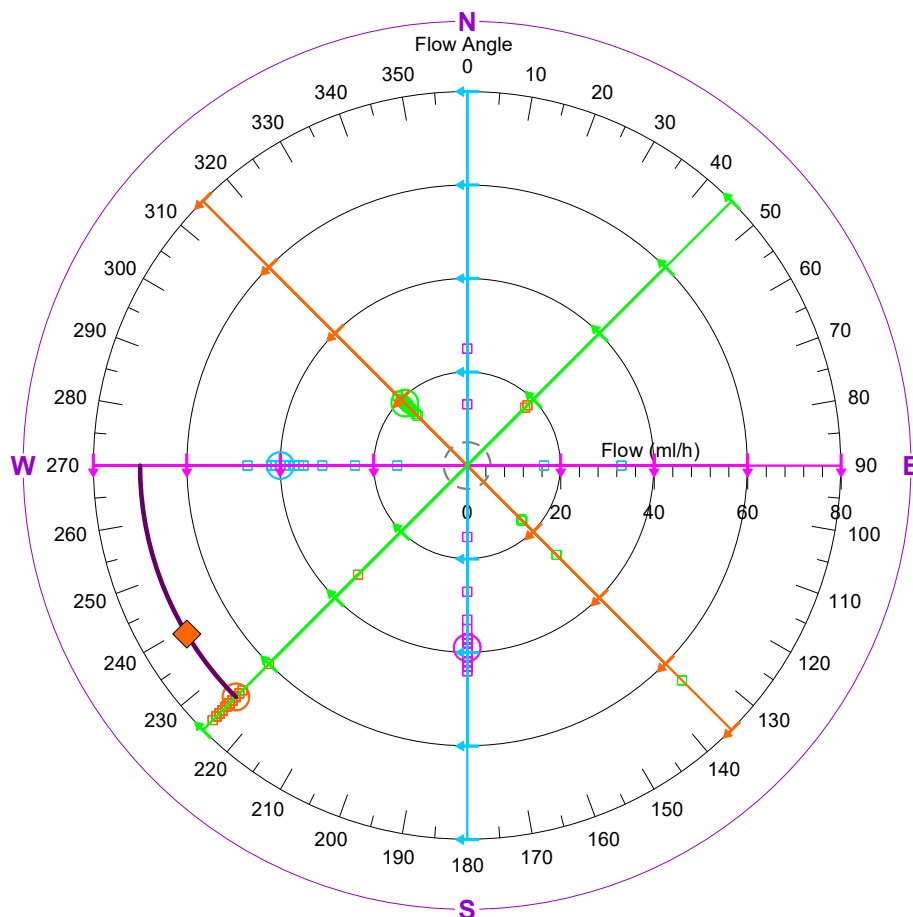


Figure 2 determination of direction of transverse flow based on four flow guide orientation.

Discussion

The Posiva Flow Log devices can be used in boreholes drilled in bedrock and ground water observation tubes. Water conductive fractures and structures can be found and hydraulic properties like transmissivity and structure head can be estimated based on the measurements. As the hydraulically conductive fractures have been found accessories can be added to PFL probe. Water sampler can be used to collect *in situ* water samples directly from fracture or structure. Transverse flow meter can be used to measure transverse flow at previously found fracture. The transverse flow meter can be used also in ground water observation tubes that have 2 m long or shorter perforated section.

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Notes

Handwriting practice lines consisting of 20 sets of three horizontal dotted lines.

Session F

Remediation of sediments

Keynote Speaker: Hotspots that make us worry from Mercury and PCB, via PFAS, to Microplastics
- How did we get here? - *Per Erik Schultze, Marine Biologist, Norges Naturvernforbund* - *James Cook University, University of Oslo, Norway*

Trondheim harbour remediation project - *Bart Van Renterghem, Envisan, Norway*

Carbon amendment technology for in-situ sediment remediation: the good and the dark side of the force - *Jarkko Akkanen, University of Eastern Finland, Finland*

Design considerations for long-term sediment cap performance - *Rebecca Gardner, Anchor QEA, Norway*

Hotspots that make us worry From Mercury and PCB, via PFAS, to Microplastics How did we get here?

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Introduction

Most harbours and industrial fjords are heavily polluted by heavy metals and POP's. Low sedimentation rates in Norway give long natural restitution time, and a national clean-up programme was started around year 2000. Both leading up to this political decision and in the years after, ever new point sources of micropollutants have been revealed. Since the late 80ies citizen scientists from Naturvernforbundet have actively participated in hunting down, pinpointing, and publicly exposing such hotspots of micropollutants along the Norwegian coast and waterways. The senior advisor in Naturvernforbundet since 1997, before then ten years in the youth branch, tells about hands-on experiences from hunting down toxics in the field.

Materials and Methods

Experiences were gathered from several field cruises and extensive travelling with sampling, diving and site visits along most of the Norwegian coast. Interviews with pollution responsible companies, their workers and leader teams as well as deep diving in historical archives has added to the knowledge base. Naturvernforbundet has also cooperated to some extent with NGOs in Russia, the Nordic and North Sea countries and some other regions in hunting down pollution sources.

Results

Shipyards, scrap metal yards and paint factories turned up as main sources of PCBs. Wood pulp factories for Mercury. Later firefighting training offshore and onshore was revealed to be major PFOS and PFAS hotspots. The last two years microplastic is the hot topic, also here a mix of old sins and ongoing activities, and several pointsources now have to stand up and be counted.

Discussion

Naturvernforbundet asks what can be learned from these decades of pollution sourcing and remediation, in particular regarding precautionary action from the industry and authorities.

Some suggestions of relevance to researchers and consultants in the sediment field:

- Expect to be surprised, not to find nothing
- Sampling is of little value without pollution-historical research and guiding
- Never expect that the polluters have actually already solved their issues, or really want to
- For consultants in particular: Don't jump too fast to the "no risk" conclusion
- Take the residents into account; people and fauna. What do they know? What should they know?

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Some readings in English on the Naturvernforbundet experiences to be found among "publications" on <https://no.linkedin.com/in/per-erik-schulze-48b092b>

RENERE HAVN - REMEDIATION OF TRONDHEIM HARBOUR

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Abstract

Emissions over the last decades resulted in highly contaminated sediments in Trondheim harbour with effects on the local environment, representing a risk for pollutants spreading to other areas in the harbour and the fjord system. Envisan, the environmental subsidiary of the Jan De Nul Group, was awarded the Renere havn project by Trondheim Kommune and Trondheim Port Authority. The project is one of the largest harbour clean-up projects in Norwegian history and is supported and controlled by the Norwegian Environmental Agency.

The Renere havn project aims to halt the spread of contamination through sediment particles in the water and to restore the port basin to its required sailing depth. Dredged sediments from three areas were partly disposed in an underwater cell and partly re-used for land reclamation. Four large areas of the port were then capped with a gravel layer to prevent the further spread of residual contamination. After the remediation works, parts of the harbour will be redeveloped into residential areas and marinas.

Introduction

The sea bed in Trondheim is up to highly contaminated by heavy metals and persistent organic pollutants such as zinc, lead, copper, PAH, PCB and TBT, which accumulate in the food chain, representing a risk for human health. Due to this risk, the Norwegian Environmental Agency identified Trondheim as one of the 17 prioritized areas for clean-up.

After an extensive preparatory study and design phase to map the contaminated areas and select the best remediation methodology, the actual clean-up could start in spring 2015. Unstable quays, bridges, old wooden buildings and structure from the 1800's limit the execution of dredging and capping as well as the future sailing depth in Nyhavna and Kanalen. Because the area is very sensitive due to geotechnical instability and landslides, capping had to be done in thin layers in IISVika.

Materials and Methods

Remediation took place in four major areas: Nyhavna, Brattørbassenget, Kanalen and IISVika. These areas with a total area of approximately 380,000 m² were capped with clean crushed limestone. Dredging took place in Nyhavna, Brattørbassenget and Kanalen to create the necessary sailing depth for commercial ships and leisure boats.

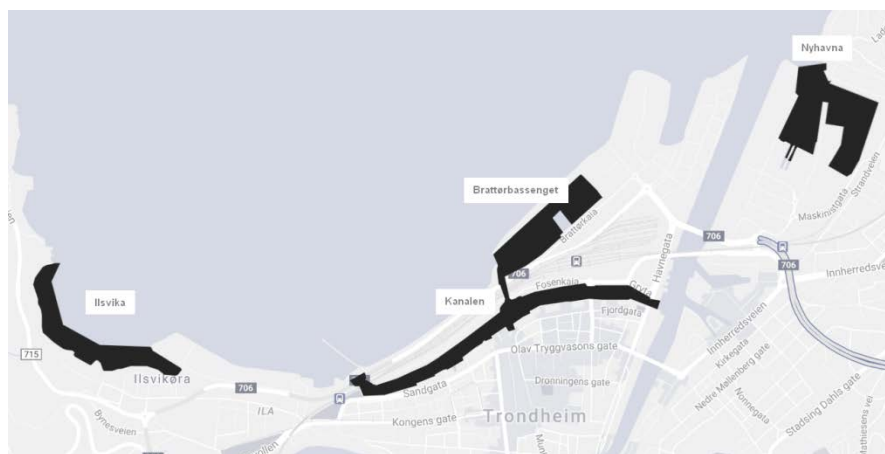


Figure 1: Project remediation areas.

Before dredging and capping could take place the project areas had to be checked for foreign objects on the seabed. This included surveys using side scan and magnetometry for unexploded ordnance dating from World War II in the project area where a former German U-boat bunker is situated.

Sediments were mainly sandy loam. Thickness of the layer to be dredged was up to 1.5 meter. In order to minimize the potential spreading of sediments during dredging, a backhoe dredger with a closed environmental bucket was used. Transport to the disposal areas of sediments took place in watertight elevator barges.



Figure 2: Dredging and transport equipment. In background disposal works are ongoing.

Two disposal areas in Nyhavna were designed to store the dredged sediments. An old floating dock site with a maximum depth of -12 m LAT could accommodate 50,000 m³. Disposal was done with a closed grab behind a silt screen. Once filled, the cell was sealed with geotextile and capped the same way as the rest of Nyhavna. Around 25,000 m³ could be sealed within a 7,000 m² reclaimed parcel (strandkantdeponi) which is part of the broader urban redeveloping plans for Nyhavna. The reclaimed parcel's perimeter dike was constructed with geobags filled with sediments and recycled soil from urban construction sites, and different grading of armour stone sourced from a quarry near Trondheim. About 7,000 geobags were filled using a double hopper system and carefully placed in the dike's core. A geotextile and a stone filter layer were constructed between the perimeter dike and the disposed sediments in order to have a 3 meter thick buffer layer between the contaminated material and the

surrounding environment. The sediments were sealed off on the top by a geo membrane and quarry stone.

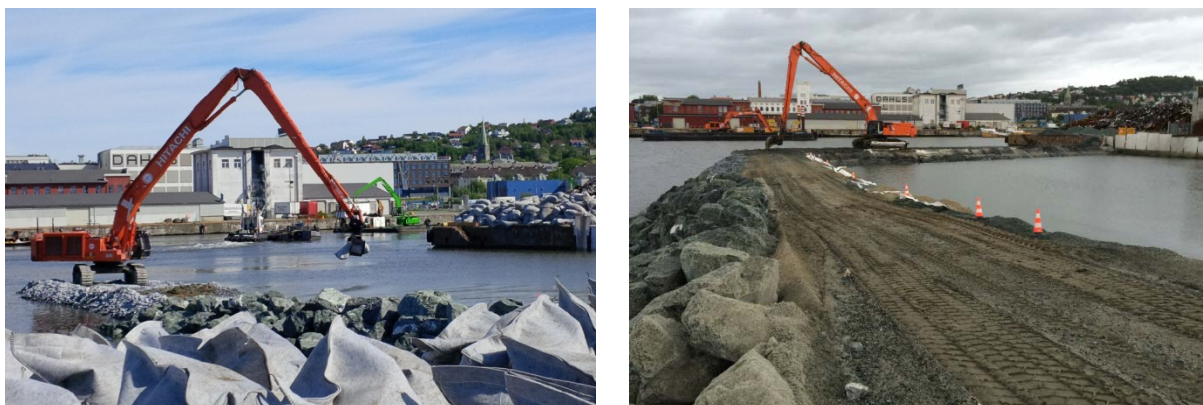


Figure 3: Construction of perimeter dike with geobags and quarry armour

Limestone from a quarry in Verdal near Trondheim was used to cap the project areas. The capping layer is designed as a physical barrier to prohibit resuspension of contaminated sediments, organisms feeding on the contaminated seabed and the diffusion of pollutants through layers of sediments before reaching the water column. The limestone was shipped in bulk carriers from Verdal to the storage areas in Trondheim harbour.

Depending on the grain size of the capping material it was installed on the sea bottom by rainbowing from a capping vessel's bow after mixing with sea water, or by spreading from a small barge equipped with bottom hatches. In areas which were difficult to reach such as under the U-boat bunker, a floating pipeline system with a spreader head was connected to the capping vessel's pumping system. The capping vessels were loaded with conveyor belts. Depending on the estimated impact of ships passing in the areas, the designed capping layer thickness varied from 10 cm to 70 cm. Thickness of the capping layer was measured by diving inspections and multibeam echo soundings.

All dredging and capping works were strictly controlled to be within turbidity criteria given in an environmental permit. When turbidity exceeded the limit, water samples were taken to determine the characteristics of the suspended solids in the water. In certain project areas, no works could take place between mid of May and early September in order to not interfere with the migration of salmon in the river. All works were subject to time specific noise regulations set in the environmental permit.

Results

A total amount of about 52 ton foreign objects such as concrete blocks, steel piles, bikes or tires were removed from the project area. No unexploded ordnance was found which took away the concern for project delays from finding and disposing them.

About 75,000 m³ was dredged in the overall project and, of that amount, 25,000 m³ was disposed in the land reclamation parcel, and the rest in the underwater cell. Dredging and disposal took place in close coordination with Trondheim Port Authority and the speed boat ferry company in order not to hamper regular ship traffic. Dredging went without major technical or planning issues.

Due to the physical characteristics of the sediments, mainly the stickiness, filling and handling of the geobags was challenging. Once this hurdle was cleared the construction of the perimeter dike, filling

with dredged sediments and sealing went smooth thanks to a well-coordinated 'just in time' logistical process. Once sealed the strandkantdeponi is used as storage area for capping material.

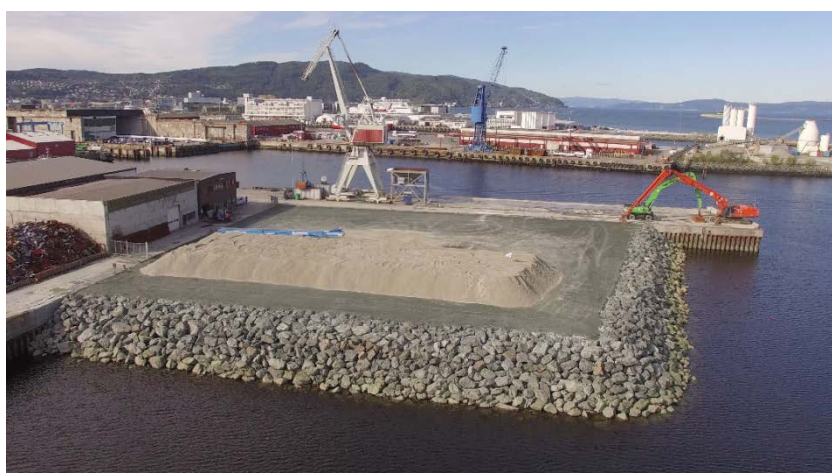


Figure 4: sealed strandkantdeponi used as storage area for capping material

A total of about 139,000 m³ capping material was spread to the seabed. The achieved capping layer was in general a flat and continuous layer. In Ilsvika, a thin layer of only 10 cm had to be placed up to 20 meter deep on a sea bottom with steep slopes. The required capping thickness could be achieved although some over capping had to be performed to compensate sliding down of material into deeper areas.

Monitoring shows periods of increased turbidity within each area, and that turbidity is influenced by methods, season and tidal currents. Fines of limestone staying in suspension caused the longest periods of high turbidity. Water samples show equal or more contaminated particles when dredging, and equal or less when depositing and capping, all compared to background levels.

Discussion

The Renere havn project had some challenges. Not only strict environmental regulations, but also careful coordination with multiple stake holders had to be taken into account. In Kanalen, buffer zones between dredging work in one sector and ongoing capping work in another had to be defined, and the whole works planned, in compliance with the water current bringing fresh water and seawater in on three different places. At the same time, the work had to be executed in coordination with bridge openings and more than 380 private boat owners.

Due to environmental harm from spreading contaminated seabed while working, turbidity could only pass 10 NTU above background level for twenty minutes at a time. Even though the monitoring stations were placed right above seabed level to monitor resuspension instead of added clean capping material, it was impossible to place the desired filter layer of fine particles within this regime. Hence, it was decided to raise the level of allowed turbidity up to 20 NTU within four hours after first thin layer of limestone had capped the contaminated sediments and prohibited resuspension from further work.

Due to a good collaboration between Envisan and Trondheim Kommune, the Renere havn project could be completed in spring 2016. Trondheim harbour is now one of the cleanest harbours in Norway.

CARBON AMENDMENT TECHNOLOGY FOR *IN-SITU* SEDIMENT REMEDIATION: THE GOOD AND THE DARK SIDE OF THE FORCE

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Abstract

For the past decade there has been fast development in the research and use of activated carbons and other carbon based sorbents on *in-situ* remediation of sediments contaminated with hydrophobic organic pollutants. It has been shown that activated carbon can efficiently reduce bioavailability of hydrophobic organic contaminants. However, activated carbon can have also secondary adverse effects on benthic organisms, especially on those that feed on sediment particles. In addition, other general aspects of the remediation method will be discussed.

Introduction

Bottom sediments are important part of aquatic ecosystems serving many purposes including acting as sinks of many chemical contaminants such as hydrophobic organic chemicals (HOCs). Unfortunately, in many cases the contaminated sediments act also as sources of chemicals, long after the original source of contamination has stopped. So far, there has been only few remediation methods for contaminated sediments. The two main traditional approaches have been dredging and capping. In dredging contaminated sediment is removed from the aquatic environment and handled in some way e.g. capsulated in a landfill. All phases contain risks and costs are quite high. In capping contaminated sediment is physically isolated from the aquatic ecosystem with up to 50 cm or even thicker layer of clean sediment, sand or some other material on top. However, these methods don't necessarily work in every situation and the remediation actions can be a burden to the ecosystem (e.g. Weston et al. 2002).

Magnitude of the risks of HOCs vary depending on sediment quality primarily through variation in bioavailability. The sediment quality characteristics controlling the bioavailability have been quite extensively studied, but single measure to predict bioavailability has not been found. Organic matter was first identified to be important, in terms of both quantity and quality. Later on it was noticed that condensed black carbon has a high sorption capacity for HOCs and thus in certain circumstances could be important fraction in sediment to limit bioavailability of HOCs. Following this lead there has been fast development over the past decade in the research using activated carbons (AC) for *in-situ* remediation of sediments contaminated with HOCs. The idea behind the method is that the available contaminants in sediments will be strongly bound by applied carbon amendments thus lowering their bioavailability and transport (reviewed for example in Ghosh et al. 2011, Patmont et al. 2015). Despite of this development and demonstrated efficiency of the technology, there are still open questions and concerns related to different aspects of the method including possible environmental risks of the remediation materials.

We have studied the possible adverse effects of carbon based sorbents mainly activated carbon on benthic invertebrates along with the effectiveness in remediation of PCB-contaminated sediments. In addition, other aspects of the method will be discussed.

Materials and Methods

Sorbents for remediation

Bituminous coal-based activated carbons were used in three different particle sizes: PAC (powdered, < 63 µm), MAC (mid-sized, 63 – 200 µm) and GAC (granular, 420 – 1700 µm). Depending on the research question and particle size sorbent concentrations ranging from 0.05 to 15% per dry weight of the sediment. In addition, coconut shell-based activated carbon as well as wood-based biochar were used in our studies.

Sediments

Both uncontaminated and contaminated sediments were used in the tests (Table 1). The clean sediments included both natural and an artificial sediment. Tervajoki River runs to Lake Kernaalanjärvi and the origin of PCBs is the same. Viinikanlahti Bay belongs to different system and the PCB-congener composition is different from the two previous sediments.

Table 1. Characteristics and locations of the test sediments. Total organic carbon (TOC) varied among different sample batches.

Sediment source	Location	Code	TOC (g/kg dw)	ΣPCB 20 congeners (mg/kg sed. dw)
Artificial sediment	Not applicable	AFS	1.4-5.4	not measured
Lake Höytiäinen	N 62° 41' 21", E 29° 40' 34"	HS	28.0	not measured
Lake Kernaalanjärvi	N 60° 85' 44", E 24° 64' 21"	KJ	7.5-8.2	3.4
Tervajoki River	N 60° 82' 34", E 24° 63' 52"	TJ	41.5-55.6	2.6-7.6
Lake Pyhäjärvi, Viinikanlahti Bay	N 61° 48' 97", E 23° 76' 70"	VL	36.7-42.0	6.3-6.6

Chemical availability

Freely dissolved sediment pore water concentrations of PCBs were analyzed with coated vial method (e.g. Mäenpää et al. 2015). Pore water concentration reflects the availability of PCBs in the sediments.

Biotests

The biotests had two roles in the studies. First one was to reveal the remediation potential i.e. the primary effects of the sorbents by testing the effects of sediment applied AC on bioaccumulation of PCBs. This was done by conducting bioaccumulation studies. The other was to reveal possible adverse i.e. secondary effects of the sorbents in the sediments. Survival, feeding rate (measured as egestion rate), biomass, lipid content, reproduction, development, emergence (from larvae to adult) and gut microvilli damage were used as end-points in the sediment ecotoxicity tests. Oligochaete worm *Lumbriculus variegatus* and non-biting midge *Chironomus riparius* were used as test organisms because they are widely used in ecotoxicology, represent important groups present in aquatic sediments as well as the fact that both feed on sediment particles, which makes them prone to adverse effects of the sorbent particles in sediments.

Results

Our studies showed that AC has adverse effects on benthic invertebrates and that the effects are related to the concentration and particle size, smaller size particles having greater effects (Nybom et al. 2012). In addition, sediment quality played a role. The effects were lower in AFS, where the organisms thrive, than in the natural HS sediment. The source of AC (fossil vs. biomass) did not play a role (Abel et al.

2016). On the other hand, AC was shown to efficiently reduce freely dissolved pore water concentrations and bioaccumulation PCBs in the study sediments (Nybom et al. 2015). The remediation efficiency and adverse effects were lower in TJ sediment with higher organic carbon content compared to that of KJ. This was evident despite of the application method thin layer vs mixed into the sediment (Abel et al. 2016). Mixing AC into the sediment reduced bioavailability of PCBs more efficiently than a thin layer cap. In a three year aging test AC was shown to maintain its efficiency during that time period (Nybom et al. 2015). However, it also maintained the properties that cause the adverse effects on benthic organisms. We were also able show that AC treatment reduces the transport of PCBs from sediment to benthic larvae and also adult midges thus protecting the terrestrial food chain as well (Nybom et al. 2016).

Discussion

All sediment remediation methods have drawbacks, contain risks and do not work in every situation (e.g. Weston et al. 2002). This statement applies also to the activated carbon based technology. Its efficiency has been demonstrated already in many laboratory studies and also in field experiments or full scale remediation projects (Patmont et al. 2015). Depending on the site specific conditions application of sorbents can be difficult (water depth, currents) as the most common ways being a thin layer or mixing as such on/to the top of the contaminated sediment. Alternative would be to apply the thin layer with AC incorporated into mineral/sediment material. In addition, AC can be added to the traditional capping materials to improve the efficiency and with different stripping (AC removal) methods it could be used for sludge/sediment treatment for contaminant removal (e.g. Han et al. 2015).

Thus, it has been quite well established that AC can be used to reduce the risks of HOCs in sediments and therefore can be used for remediation. However, as our and other previous have shown AC can have adverse effects on benthic organisms. The effects depend on type of the organism and characteristics of the sediment, but organisms feeding on sediment particles appear to be the most sensitive (Nybom et al. 2012, Janssen and Beckingham 2013, Nybom et al. 2015). The mechanisms of the adverse effects have not been confirmed yet. This should be considered in site characterization during remediation planning.

One of the aspects to consider in here are sediment quality guidelines. If we have such for a contaminant and the value is based on total sediment concentration (instead of bioavailable concentration), we have a problem. This remediation method does not actually reduce the total concentrations significantly, on the contrary it may even reduce degradation. Bioavailability has not been really included into current risk assessment procedures and that affects also applicability of sorbent based remediation methods. This is partly due to lack of standardized methods for bioavailability measurement.

All things considered, the recently introduced method based on sorbent amendments offers a noteworthy choice for remediation of contaminated sediments. However, as all remediation methods, this one is not suitable in all cases and site-specific evaluation of effectiveness and risks with clearly defined remediation goals are always needed.

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Design Considerations for Long-term Sediment Cap Performance

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Background

Throughout Scandinavia, many industrial properties are being transformed from underutilized, contaminated spaces into thriving mixed-use areas that are accessible to the public. In many cases, these properties are located adjacent to waterways that are also contaminated. Restoration of these sites poses a unique opportunity to create areas for habitat enhancement and community engagement with the water resource. However, prior to realizing these benefits, it is necessary to ensure that the investment will be protected over time. For cases where the contaminants should be managed in situ, there are several engineering analyses that can be performed to assess long-term performance of the sediment cap. These assessments include modeling of geotechnical stability, physical forces generated by currents, waves and ship propellers, and contaminant fate and transport.

Aim

The long-term success of a sediment cap is dependent on its physical stability and ability to prevent migration of contaminants over time. This presentation will provide the audience with an overview of the engineering analyses that are available to assess long-term sediment cap performance related to these design considerations. The general principles of the assessments, as well as the field and laboratory data necessary to reduce uncertainty in the engineering models, will be reviewed. Case studies from recent projects in Norway and Sweden will be used to illustrate the design process in practice.

Conclusion

Sediment caps are an effective method for managing contaminants in situ; however, the long-term performance of the cap can be compromised if important considerations are ignored during design. A range of engineering evaluations are available to assess physical stability and migration of contaminants through the cap. Although it is not necessary to employ all of these evaluations for each project to be successful; this presentation will provide the audience with a preliminary understanding of when these evaluations may be beneficial to include during design.

Notes

Handwriting practice lines consisting of 20 horizontal dotted lines.

Session G

Military areas

A project to improve environmental protection on heavy weapons ranges – *Terhi Svanström, Defence Command in Finland, Finland*

Mobility and transport of lead (Pb), copper (Cu) and antimony (Sb) in a peat land contaminated by shooting activities – *Gudny Okkenhaug, Norwegian Geotechnical Institute, Norway*

Immobilization of Pb and Sb in shooting range soil: column experiment with industrial waste iron-based sorbent – *Hilmar Sværsson, Lindum, Norway*

A PROJECT TO IMPROVE ENVIRONMENTAL PROTECTION ON HEAVY WEAPONS RANGES

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Abstract

National defence is a task defined in legislation and it includes military education and training. Training in real surroundings with real weapons is indispensable and cannot be completely replaced with simulations. Training with real weapons is also a crucial part of maintaining and demonstrating credible defence.

There is a growing need to develop management practices for heavy weapons ranges because problems with i.e. explosive residues in groundwater have emerged and are forming a severe threat for mission sustainability. Cooperation between nations can partly compensate budgetary constraints.

An international project was established to develop the environmental protection of heavy weapon ranges (EPHW). In the project the whole scope of environmental aspects will be covered: noise and vibration management, soil and water protection and nature values protection. There are participants from Finland, Sweden, Norway, Denmark, United States and Canada.

The result will be a guidance document for establishing the sufficient level of environmental protection and feasible risk management and mitigation methods for training areas where training with heavy weapons and explosions is carried out.

Introduction

Training with heavy weapons requires large training areas. On one area there might be training with missiles, artillery, tanks, anti-tanks, rocket launchers, hand grenades etc. Some of them have fixed firing positions and target areas, while some require mobility. Assault rifles are used not only on fixed small arms ranges but also on training areas during fighting training. Explosion training is usually done on fixed places but smokes and small detonations can be used to simulate gunfire wherever training takes place. In addition there might be air-to-ground shooting and naval gunfire support on land areas.

Above mentioned activities cause environmental effects. The most evident effect is low frequency noise and vibration. Emissions of propellants and explosive ammunition leave traces of energetic compounds in the top soil. Training areas have often significant nature values and important groundwater resources. The environmental impacts cannot be completely avoided, but with smart planning and feasible measures they can be managed and mitigated. Nowadays groundwater areas and other important environmental aspects are taken into account when planning sites for new training activities. Problematically many training areas have been in military use for decades, starting long before the current level of environmental consciousness and understanding what harm the training could cause to local environmental values.

Environmental permits are a common way to ensure that environmental aspects are taken into account and the harmful effects mitigated, but for areas used for military training this approach has challenges. The guidelines for military specialties such as heavy weapons noise and munition concentrations are often ambiguous or non-existent. On the other hand general requirements of environmental legislation

have tightened in recent years. There is a struggle going on to reach balance between sufficient environmental protection and maintaining the military training possibilities.

Methods and materials

Review studies have showed that there is a lack of coherent knowledge on the possibilities to reduce the environmental impacts of heavy weapons. On some areas there is an abundance of information whereas on some topics there would be a need for more in-deep studies. Most of the knowledge is scattered and cannot be easily found at one, collected source. The goals of the project include collecting and analyzing existing data and to assess the possibilities to use solutions that might already be in use elsewhere (e.g. road building, chemical industry) to reduce the impacts of military training.

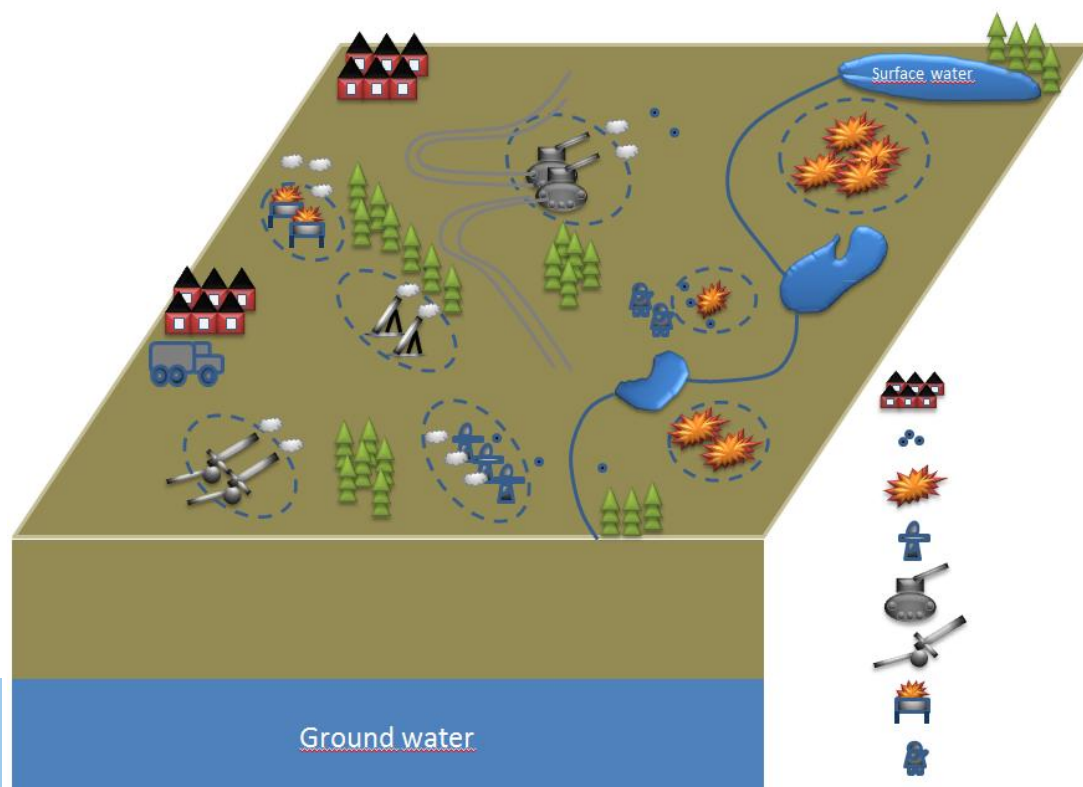
In Nordic cooperation forums it has been long discussed that there is a common need to develop environmental protection on heavy weapons ranges. Therefore an international project was established in 2014. The first workshop was held in the European Conference of Defence and the Environment (ECDE) in June 2015 in Helsinki. The project will last until the end of 2017 and two workshops will be held annually. The work is divided in to five subgroups: noise & vibration, soil & water, nature values, user requirements and legal requirements. The entity of the project will be guided by a steering board. The project has participants from Finland, Sweden, Norway, Denmark, United States and Canada. The participants include operational and environmental experts from the defence administration as well as environmental authorities.

The result of the project will be a guidance document *Technical and practical solutions for environmental protection of Heavy Weapons Ranges*, which will define case-specific measures and practices needed for sufficient environmental protection. This guidance will work as a tool for training operators, environmental experts and environmental authorities. The guidance will help to define the correct level of environmental protection, describes possibilities to manage risks and ways to compare and choose the correct site-specific approach. There will also be a chapter of standard environmental management procedures which form the base level of what should always be taken into account on heavy weapon training areas.

In the following chapter the focus will be in the soil and water protection although the noise management and the consideration of nature values are elaborated equally in the project.

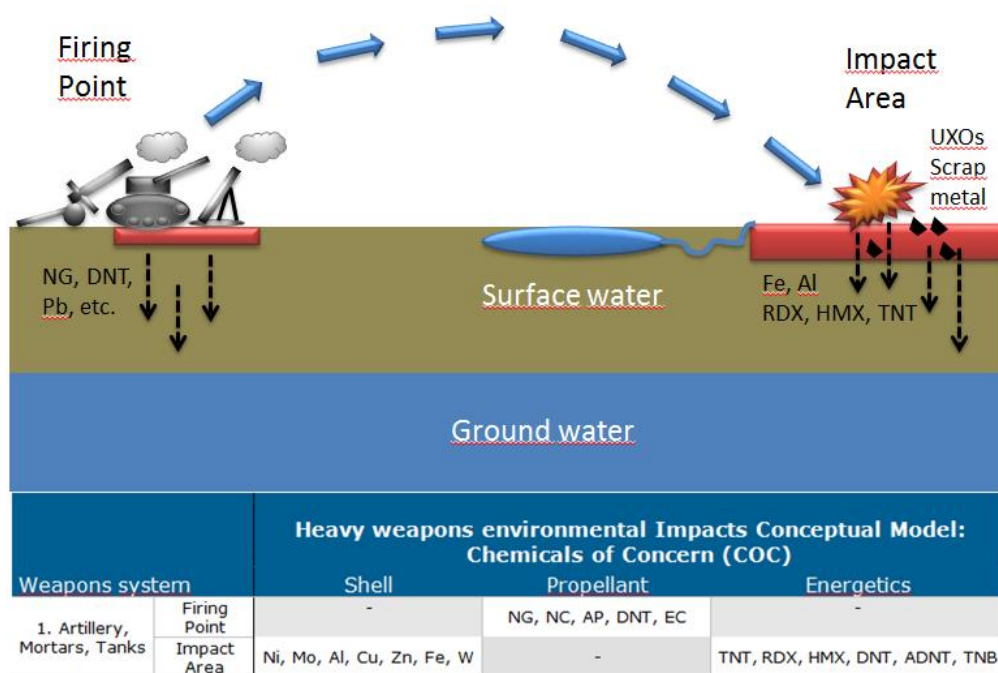
Results: Risk Identification for Soil and Water

As a starting point for further work conceptual models are drafted to clarify the situation in the heavy weapons training areas. Generic training area maps are first delineated, including the most common environmental conditions and environmentally relevant training activities (picture 1).



Picture 1. Heavy weapon shooting and training range, conceptual model for environmentally relevant activities











Weapon system specific conceptual models for each sub-site further describes the chemicals of concern and their transport routes through relevant environmental compartments. For example in the case of mortar shooting training, the sub-site specific CM shows how and which substances could be released to the environment in the firing point and in the impact area (picture 2).



Picture 2. Site-Specific Conceptual Model of artillery, mortars and tanks

The site-specific CM is supported by Risk Identification Chart (RIC). In RIC the characteristics of the training sub-site (soil type, groundwater status, surface water routes, nature values) are identified and

rated for their environmental significance (traffic lights). Also, possible receptors (military, recreational, residential, environment) are identified and rated for the potential of been exposed to emissions caused by training activities (picture 3).

Risk Identification Chart											
Emission Characterization			Site ID				Exposure ID				Identification of Risks
Weapon System	Sub-site: Firing Point	Chemicals of Concern	Soil Type	Groundwater	Surface water	Nature	Military	Residential	Recreation	Environment	
Mortar		NG EC etc...									Soil maintenance, no groundwater risks, surface water monitoring, ERA, restrictions and guidance for recreational use
Howitzer		NG DNT EC	etc...				etc...				

Picture 3. Example of the Risk Identification Chart: Mortar firing point.

For each weapon system, the munition constituents that are supposed to cause emission (Chemicals of concern) are chosen on the grounds of residues deposition tests. Also, explanatory preconditions for classification of site and exposure identification are given to make the rating more easy and uniform. In the concluding identification of risks, practical recommendations for range management are given for those environmental compartments where risks are actualized. Oftentimes additional soil and water investigations and quantitative risk assessments are made to further define the environmental circumstances of the site.

Conceptual modeling and risk identification provide qualitative information for decision making to implement practical and cost-effective approaches on range management. Also, this approach makes it possible to prioritize the sub-sites for their risk management and mitigation needs and scheduling.

If the risk identification indicates that there is a need to mitigate the risks, the next step is to plan the appropriate method for it. In the guidance document there will be a collection of possible risk mitigation methods and they will be characterized in such a way that a suitable one can be chosen for each case. Permanent physical structures to prevent contamination load to the environment are not feasible or cost-effective because training areas are large, the training activities are mobile and the shooting impacts are more or less destructive. Instead possible measures could be for example collecting and treating run-off waters from the target areas, on a small scale treating top soil by destroying energetic remnants with heat and of course representative monitoring of the contaminant load. Also by designing the use of the areas the strain on the environment can be minimized.

Discussion

The result of the project will be guidance on how to define the correct level of environmental protection on a training area and what measures would be the most beneficial and feasible for each case. However the document cannot be in a strict sense a Best Available Technology Reference Document since the solutions are not yet tested and proven in the way meant by the BAT definition. Also it is acknowledged during the planning of the project that not everything can be fully covered in this work. Possible gaps will be identified within the project and recommendations for further studies can be made.

All the suggested technical solutions and management practices might not be possible in every nation due to differences in legislation and regulation. The project will include a comparison of the legislation in the participating nations. The outcome will hopefully help in defining functional legislative framework for environmental protection when training with heavy weapons.

MOBILITY AND TRANSPORT OF LEAD (Pb), COPPER (Cu) and ANTIMONY (Sb) IN A PEATLAND CONTAMINATED BY SHOOTING ACTIVITIES

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Abstract

The aim of the present study was to investigate the distribution and transport of Pb, Cu and Sb in peatland contaminated by shooting range activity. Furthermore we wanted to test the hypothesis that large ponds in shooting range areas may have a remediation effect due to sedimentation of particle bound contaminants. To do this we carried out a field study at a closed shooting range facility in Norway, sampling peat soil samples for various extractions, establishing groundwater wells for groundwater samples and automatic monitoring of groundwater level, sampling of water and sediments in surface water.

High total element concentrations were observed in the top layer of the peatland area with a low vertical transport of the contaminants. Porewater sampling, chemical extractions and passive samplers (DGTs) showed low solubility of the contaminants with a small bioavailable fraction contaminants compared to total concentrations. However, elevated metal and Sb concentrations were observed in the groundwater.

Hydrogeological investigations and modelling showed that the main contaminant transport mainly occur in the upper layer of the peatland area. Increased total and bioavailable concentrations in the stream crossing the shooting field, indicated a substantial contaminant spreading. Lead and Cu were generally associated with dissolved organic carbon (DOC). Low particle transport and small sedimentation rates in a downstream pond, indicated that sedimentation was unsuitable as a remediation option in this area.

Introduction

Small-arm shooting ranges represent sites with a significant input of metals and metalloids into the environment, where lead (Pb), copper (Cu) and antimony (Sb) are among the main contaminants. Due to weathering and corrosion of the bullets leaching of Sb together with heavy metals from shooting range areas may represent a serious long-term environmental risk (Okkenhaug et al., 2013). Numerous shooting ranges in Norway are located in remote areas with a large percentage of peatland. Peatlands are areas with high groundwater level, high organic content and low pH, which make remediation challenging. To understand the solubility and transport mechanism of contaminants is crucial regarding possible remediation option in such areas. However, studies on shooting range contaminants in peatland areas are scarce in literature.

The aim of the study was to investigate the distribution, binding and transport mechanism of Pb, Cu and Sb in contaminated peatland by using different extraction and fractionation methods for soil, water and sediments. Furthermore we wanted to test the hypothesis that large ponds in shooting range areas may have a remediation effect due to sedimentation of particle bound metals and Sb.

Materials and Methods

The field site is a closed shooting field (2.7 ha) located at the Terningmoen military shooting range in Elverum, Hedmark county, South Norway (60.87 °N; 11.50 °E). An open peatland covers the area between the backstop berm and the firing line, whereas the backstop berm consists of larger stones and sand. The peatland soil has an organic content (TOC) of ca. 50 % and is slightly acidic (pH: 5.2 – 5.4). Field work was carried out in 2014 – 2015, including sampling of peatland soil, peat soil porewater (MacroRhizon samplers), pond sediments, groundwater (wells) and surface water.

To investigate the distribution of Pb, Cu and Sb in soil and sediments, various single extractions were carried out (CaCl₂, NH₄-acetat, oxalate extractions and total acid digestion). Furthermore to determine the freely dissolved and labile fractions of metals and Sb in peat soil a pot experiment using passive samplers (diffusive gradient in thin films, DGT).

Surface water samples from the stream crossing the polluted peatland were sampled by automated pumps (ISCO, USA). Freely dissolved and labile metals and Sb in surface stream water were determined using DGT. Metals in water samples, soil- and sediment extracts were determined by ICP-OES (Optima 5300 DV) or ICP-MS (Elan 6000).

The results from the monitoring of the water table, together with the hydraulic conductivity measured in the laboratory, were used to build numerical models and simulate the groundwater movement. These models were further used in order to evaluate the residence time of the contaminants in the peatland and to assess the impact of possible remediation. The numerical simulations were carried out using Seep/W and C/Tran (GeoSlope Int., 2014).

Results and discussion

The highest total concentrations of Pb (1 400 mg kg⁻¹), Cu (843 mg kg⁻¹) and Sb (110 mg kg⁻¹) were observed in the top layer (0-15 cm) of the peatland area with a low vertical transport of the contaminants in the peat soil system. These high concentrations could be related to bullets fragments as well as elements sorbed to the soil matrix. The total content of metals and Sb in the peat soil samples decreased significantly with increasing distance to the target backstop berm. This is in accordance with literature, where the highest concentrations at shooting ranges are found in connection with the backstop berm (Sorvari, 2007).

The amount of CaCl₂-extractable Pb (0.1 – 0.4%), Cu (0.4 – 5.6%) and Sb (0.6 – 1.5%) in peat soil as well as NH₄-acetat extractable fractions of Pb (6 – 17%), Cu (1 – 5%) and Sb (1 – 5%), indicated a low fraction of weakly-sorbed species and readily bioavailable elements compared to total concentrations. Analysis of peat soil porewater and passive sampling of soil with DGT showing relatively low concentrations, supported this. The main fraction of contaminants were associated with Fe/Al oxyhydroxides in soil, and most likely organic material.

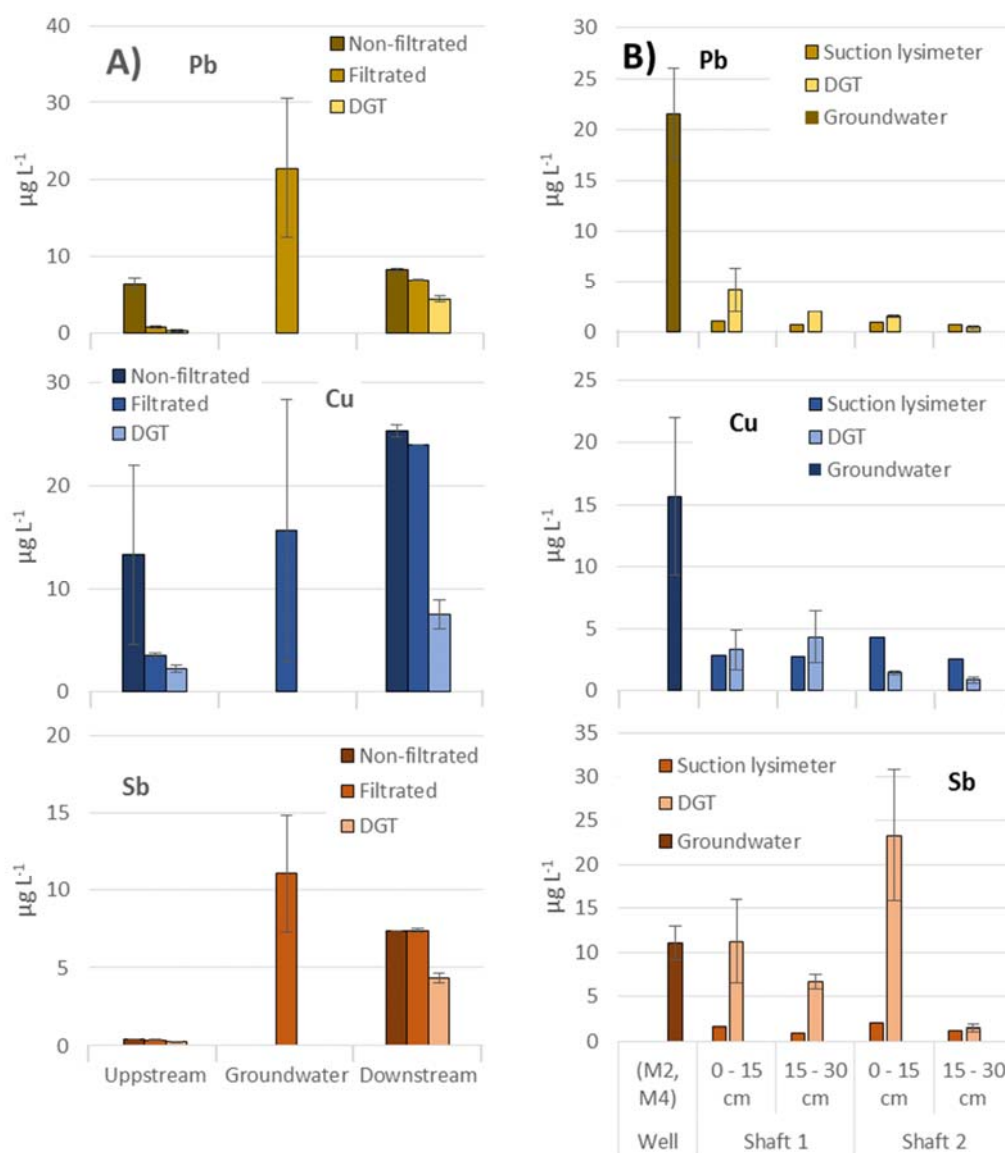


Figure 1 (A): Concentration of Pb, Cu and Sb upstream, in groundwater wells and downstream in non-filtrated, filtrated and passive samplers (DGT) in the polluted peatland. (B): Concentration of Pb, Cu and Sb in filtrated groundwater well samples as well as in the porewater sampled by DGT in pots or suction lysimeters.

Despite high total soil concentrations, low concentrations of Pb, Cu and Sb were observed in porewater with little difference between the peat soil samples, (suction lysimeter of Shaft 1 and 2 in Figure 1). The highest porewater concentrations were observed for Cu, whereas Pb showed the highest total concentration in peat soil. It has previously been shown that complexes with Pb and dissolved organic matter (DOM) has a lower solubility compared to Cu, most likely due to a stronger complexation (Tipping et al., 2003).

Variations in the groundwater concentrations were observed in wells located in the peatland (M2, M4), with average concentrations showing substantial higher concentrations of Pb, Cu and Sb compared to

porewater (Figure 1). The reason for this could be due to the smaller pore size of the lysimeters used for porewater sampling (<0,2 µm versus 0,45 µm filter for groundwater samples), excluding higher molecular dissolved organic carbon (DOC).

Analysis of the saturated hydraulic conductivities (k_{sat}) of the peat soil samples showed large differences between the top (0-15 cm) and underlying (15-30 cm) layers with $k_{\text{sat}} \sim 4 \cdot 10^{-5}$ m/s and $\sim 7 \cdot 10^{-6}$ m/s respectively. These observations are in accordance with data from literature (Rydin et al., 2013). The results from the hydrogeological models indicated that most of the transport happens in the upper layer due to higher hydraulic conductivity close to the surface and the high groundwater table. Based on the hydrology model and calculated partition coefficient (K_d) values it could be shown that Pb, Cu and Sb will leach from the peatland area over a long term period.

Increased total and bioavailable concentrations of Pb, Cu and Sb in the stream crossing the shooting range field (Upstream, Downstream, Figure 1,) confirmed the spreading of metals and Sb described by the hydrology model, as well as indicated by the higher concentrations in groundwater samples taken from the peatland (Groundwater, Figure 1). Among the tree elements, Cu showed the highest concentrations in the stream water, whereas the Pb concentrations were lower, on the level of Sb. This was similar to the findings in the porewater, indicating a higher mobility of Cu and Sb in peatland areas compared to Pb representing the highest contamination at shooting ranges. Both Pb and Cu concentrations in the stream water correlated well with the amount of organic material (R^2 between 0.67 to 0.98), while antimony showed no such correlation (R^2 between 0.21 to 0.33).

The low sedimentation rate in the downstream pond ($\sim 0,051$ mm yr⁻¹) indicated a limited particle transport and sedimentation in the surface water of the peatland system. This was confirmed by chemical analysis of sediment profiles in the pond. Thus, making sedimentation in large ponds unsuitable as a remediation option in this area.

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Immobilization of Pb and Sb in Shooting Range Soil: Column experiment providing an Industrial waste Iron-based sorbent.

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Abstract.

Shooting ranges are sources of lead (Pb) and antimony (Sb) contamination to soil. In this study, we investigated if low cost industrial waste could be used as a sorbent to immobilize Pb and Sb. The sorbent contain oxides of iron (Fe, 26%), aluminum (Al, 5%) and calcium (Ca, 5%). Total concentrations of Pb and Sb in the test soil were 3600 mg/kg and 72 mg/kg, respectively. Total organic carbon (TOC) content was 5%. In the experiment, four different mixtures of this sorbent were tested, using 15 columns. The sorbent was either mixed into the soil or used as filter at the bottom of the column. The experiment was carried out over a five-week period. Drainage water was collected periodically and analyzed for Pb, Sb, dissolved organic carbon (DOC), Fe and pH. The retention effect of mixing 10% by volum of sorbent into the soil was shown to be approximately 60% for both Pb and Sb. When the sorbent was used as a filter at the bottom of the columns retention was about 90%. The results indicated that shifts in redox conditions during the test period, lead to increased mobilization of Sb. Such scenarios may take place in real treatment situations.

Introduction

Small-arms shooting ranges are recognized sources of heavy metal and -metalloid pollutants. The most common contaminants are lead (Pb), copper (Cu) and antimony (Sb). In Norway approximately 103 tons of Pb and 12 tons of Sb were deposited at small arms shooting ranges in 2006 [1]. Trace metals in soils are mostly partitioned in organic and inorganic fractions. The fraction of metals bound to solid solids react quickly to physicochemical changes in the soil. Such changes occur typically under shifts in pH and redox conditions, changes in DOC in pore water and even to changes in quality or quantity of solids such as iron oxides [2]. Study by Hockmann et. al [3] have shown strong seasonal fluctuation in Sb leaching from non-waterlogged calcareous soil, which seem to be driven by fluctuation in DOC and probably also bicarbonate concentrations. Another study from Hockmann et. al [4] provided evidence that transitioning from oxidative to anaerobic conditions in soils can lead to reduction of Sb(V) to Sb(III) within days to weeks. That means that Sb(V) is less stable in redox-variable soils than previously assumed. Given that Sb(III) is more toxic than Sb(V), redox condition is one of the key factors for estimating mobility, and thereby risk of leaching of Sb from soil. In landfills, there are two alternative methods by which to reduce the risk of Pb and Sb leaching from contaminated soil. The first is to collect all the seepage from the soil and purify the water. The second is amending the soil aiming at stabilizing the pollutants, thus reducing metal mobility. The second alternative may be a more cost-effective method than continuous water treatment, particularly at large scale. Both lime and phosphate amendments has successfully been used to stabilize Pb in shooting range soil [5]. In many case liming can increase soil pH, effecting a reduction of sorption capacity for the negatively charged Sb(V) oxyanion ($\text{Sb}(\text{OH})_6^-$) [5,6]. Liming also increases leaching of DOC in soils high in organic matter. Since humic acids are the major binding sites for antimony in such soils, a side effect of liming may lead to increased mobility of antimony. Phosphate competes for

sorption sites and increases mobility of antimony. When stabilizing shooting range soil it is important to immobilize both Pb and Sb. Ferric oxyhydroxides provide stable sorption sites for both Sb and heavy metals like Pb and Cu. Hence, ferric oxyhydroxides (co)precipitates both cationic and anionic substances. Both anions and cations may bind on the surface of iron oxides in two ways: specific and nonspecific adsorption [5,7]. Nonspecific adsorption is controlled by electrostatic interactions between the sorbent surface and the ions present in solution. In the case of specific adsorption, the migration of anions and cations from the solution result in inner-sphere adsorption where the hydroxyl groups coordinately bond with a single iron atom. Bonding of anions on the adsorbent surface is accompanied by the release of hydroxyl groups, which contribute to the alkalization of the soil environment [7]. The specific adsorption of anions is possible in an environment where pH is higher than the pH (pzc) of the sorbent, while the adsorption of cations can proceed in a slightly acidic environment, in which their solubility is the highest [8]. In this study, we aimed to investigate if an iron-based sorbent stemming from industrial waste could immobilize Pb and Sb from contaminated shooting-range soil. The study was performed over 5 weeks. Consecutive water extractions were taken to learn if the sorbent would immobilize the trace metals over time.

Materials and Methods

Soil material was collected from backstop berm located at Tittelsnes military shooting ranges in Sveio municipality, in Norway (UTM 59.7146301269531 N, 5.50814199447632 E). The shooting range was in use for 55 years. The climate is oceanic, with 1800 mm average annual precipitation. Mean temperature of the coolest month is 1°C and the warmest month is 14°C. The bedrock consists mostly of acidic gneiss.

Table 1, Content of TOC, Sb, Pb, Ca, Fe, Cu and pH in control soil from Tittelsnes (n=3).

	pH	TOC	Sb mg/kg	Pb mg/kg	Ca g/kg	Fe g/kg	Cu mg/kg
Soil	7,7	5%	72,7 ± 2,1	3633 ± 57,7	21,5 ± 0,2	32,4 ± 0,5	180,0 ± 10
Sorbent	11,2	-	0,7 ± 0,1	4,4 ± 0,2	52 ± 0,3	277 ± 8,8	20,7 ± 0,6

All extractions were carried out in triplicate unless stated otherwise. Acid digestion of soil samples were carried out using a mixture of hydrogen fluoride (HF) and concentrated nitric acid (HNO₃) in a ratio 1/5, with 0,25 g samples (oven-dried (105° C) in an ultraclave (260°C). Digestion of certified reference soils (2711a og 2710a) was conducted, and the recoveries were 96,5 and 100 % for Cu, 97,8 and 100% for Pb and 88% for Sb. Elemental analysis was conducted using inductive coupled plasma mass spectrometry (Agilent Technologies 8800 ICP-MS Triple Quad). The sorbent was derived from industrial waste, produced by Tinzir Titan & Iron AS based in Tyssedal, Norway. It is a byproduct of titanium and iron smelting, and consists mostly of oxides of iron, calcium, titanium, zinc, aluminum and sulfur. pH is approx. 11 and relative density is 1.5-1.86 g/cm³. The sorbent was manually sifted at 6.7 mm mesh. The columns were of stainless steel with diameter 10 cm. Columns of both 100 cm and 50 cm were used. Each soil type received 5 different treatments, with sorbent added per volume: 1) Untreated soil, 2) Soil with 5% sorbent, 3) soil with 10% sorbent, 4) soil with 5% sorbent as a filter at the bottom of the column, 5) soil with 10% sorbent as a filter in the bottom of the column. Each triplicate was made of one 100 cm column and two 50 cm columns. The soil was homogenized in a cement mixer before it was mixed with the sorbent. The sorbent was mixed into the homogenized soil by hand. The column bases had stainless steel screening (mesh size 0.5 mm) and a Weissband Rundfilter aschefrei 125 mm filter attached to facilitate gravity drainage. Whatmans 40 ashless 9,0 filter paper was placed on top of each column to spread the water evenly. Water was added manually to each column to field capacity. The columns were equilibrated in 24 hours before distilled water was carefully added in top to replace the exact volume of the equilibrium water. Water

samples were collected after approximately 2 hours. This procedure was repeated 5 times: days 1, 2, 3 10 and 45. Water samples were filtered through 0,45 μm polyether sulfon membrane filters to analysis of total Pb and Sb. Element concentrations in the collected water were determined using the ICP-MS. pH was measured manually with an Orion SA 720 pH meter. DOC was measured with Shimadzu TOC-V CPN Carbon analyzer.

Results

The results show clear differences between treated and untreated soil. The concentrations of Pb and Sb in the leached water varied from 80-150 $\mu\text{g/l}$ for Pb and from 200-450 $\mu\text{g/l}$ for Sb (figure 1). Comparatively, concentration decreased to 50 $\mu\text{g/l}$ for Pb and 120 $\mu\text{g/l}$ for Sb with 5% sorbent mixed with the soil. The 10% sorbent-soil mix significantly increased adsorption (over 10% increase) compared to 5% sorbent-soil mix.

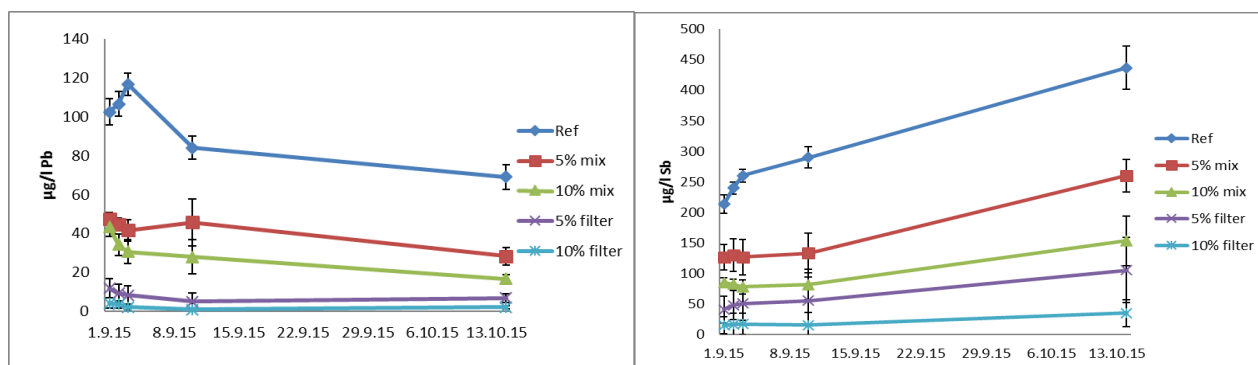


Figure 1a (Lead) and 1b (Antimony) leaching during 5 weeks column experiment. Contaminated soil from shooting ranges treated with iron based sorbent. The sorbent was either mixed with the soil or used as a filter at the bottom of the column. Sorbent was added based on volume.

The leached concentrations of Pb and Sb were fairly stable during the first days of the experiment, but after 45 days, however, the concentration of leached Sb increased from all treatments. This may be connected to changing redox conditions. Hockmann et. al [3] reported that a transition from oxidative to anaerobic conditions can lead to reduction of Sb(V) to Sb(III) in soils within days to weeks, and that

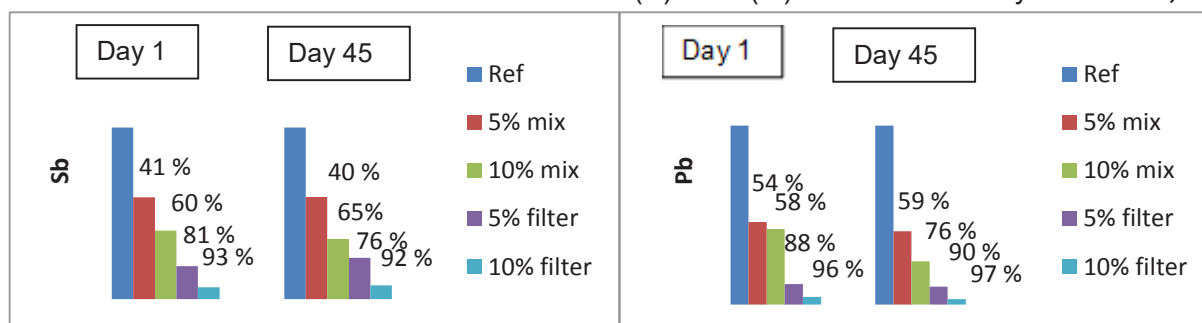


Figure 2 Retention rates of Pb and Sb in treated soils. Comparison of treatments at beginning and end of column experiment.

Sb(V) is sensitive to the redox environment. Figure 2 shows retention effects for both Pb and Sb. Interestingly, the retention efficiency remains almost unchanged even with increased leaching over the 45 days period. Effective retention in the 5% sorbent treated soil was approximately 50% for Pb and less than 50% for Sb. Increasing the sorbent additions to 10% had a greater effect for Sb than for Pb. Better retention was achieved when using the same amount of sorbent as a filter at the bottom of the columns, compared to mixing the sorbent with the soil. A sorbent filter volume corresponding to 5%

resulted in retention of approx 90% of lead and 75% of antimony. Comparatively, 10% sorbent filter volume added to the bottom of the column resulted in 95% retention of lead and 90% of antimony. The observed effect of the sorbent used as a filter compared to mixed in the soil may be incomplete contact of soil water with sorbent that the sorbent doesn't get contact with the majority of the water with less than 10% of sorbent added to the soil. All the water is forced through the sorbent when it is used as filter at the bottom. The total cumulative capacity of the sorbent filter to retain Pb and Sb remains to be determined

Conclusions

This study shows that industrial waste with high iron oxide content may be used to retain lead and antimony contamination in soil from shooting ranges. Low sorbent cost makes it plausible to consider establishing a functional method, based on an industrial waste, to stabilize contamination in soil from shooting ranges, in landfill. There is a significant effect both when the sorbent is used as a filter at the bottom of the columns and also when the sorbent is mixed within the soil profile, although our results show that the sorbent is more effective when used as filter at the bottom of the soil. We found indications of shifts in redox condition during the test period. This might cause difficulties in landfill as the stabilization Sb and Pb should be permanent and effective in both oxic and anoxic conditions.

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Notes

Handwriting practice lines consisting of 20 sets of three horizontal dotted lines.

Session H

Indoor air

Sewerage measurements in connection with intrusion pathways for contamination to indoor air -
Louise Clausen, NIRAS, Denmark

New possibilities to assess risk of exposure in indoor climates - *Ylva Sandberg, NIRAS, Sweden*

CFD Simulation of Passive Compartment Ventilation to avoid Vapor Intrusion - *Tage V. Bote, COWI, Denmark*

Sewer measurements to detect intrusion pathways for contamination to indoor air

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Introduction

Intrusion of Volatile Organic Compounds (VOC) to the indoor air often causes unacceptable impact on the indoor air in domestic houses situated on contaminated sites. When searching for intrusion pathways for VOCs to the indoor air, it is often registered that the sewers are a primary or secondary intrusion pathway for contamination to the indoor air. In order to reach this conclusion, sewer inspections and air measurements are carried out in the sewer system as well as above the water traps.

Presently, there are no Danish recommendations on how to perform air measurements in sewer systems. Accordingly, consultants and Danish Regions carry out measurements in different ways. The methods not being uniform causes that some of the results may not be comparable. Furthermore, the accuracy of the various methods is uncertain.

The Central Denmark Region and NIRAS have collaborated in a project jointly, financed by the Danish EPA and the Central Denmark Region. The project objective was to develop a recommendation/guidelines on how to perform air measurements in sewer systems and at various technical installations (toilets, sinks, floor drains etc.).

The project included the following 4 phases:

1. Collect existing data from the Danish Regions and consultants
2. Conduct lab tests at the Danish Building Research Institute, Aalborg University
3. Perform field tests at three different sites
4. Prepare recommendations on how to measure contaminant concentrations in sewer systems and above water traps.

This abstract will describe the 4 different phases and the recommendation on how to perform the sewer measurements.

Materials, Methods and partial results

Phase 1: Existing data from the Danish Regions. Initially, the 5 Danish Regions were asked about their current experience with sewer measurements to detect intrusion pathways at contaminated sites. The aim of collecting these data was to find out, how the sewer measurement was performed and the uniformity of these measurements. In total, 45 reports were gathered describing investigations at contaminated sites involving sewer measurements. Overall, it could be concluded that the sewer measurements were carried out in the following ways:

- Passive measurements in sewer wells (appx. 14 days sampling time).
- Active sampling behind water traps and in the downpipes (10-100 liters sampling volume).
- Active sampling above water traps (5-10 liters sampling volume).
- Active sampling in indoor air as a reference measurement (20 liters sampling volume).

Based on the existing data, it could be concluded that despite the missing guidelines the measurements were conducted very similarly by the different Danish Regions and consultants.

The concentration levels regarding to the existing measurements were different, and no overall conclusion could be made on concentration levels. See the figure below.

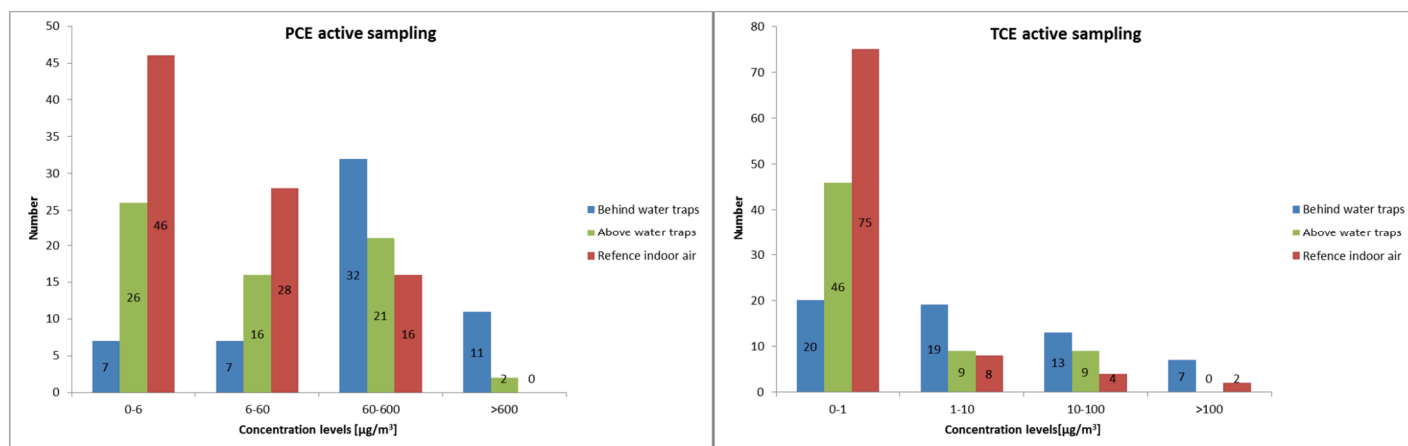


Figure 1: Concentration levels – active measurements regarding sewer systems.

Based on the gathered data it was not possible to find a standard connection between the contaminant concentrations in the sewer wells, the downpipes, above the water traps or in the indoor air.

Phase 2: Laboratory tests. The aim of the laboratory tests was to examine how the active measurements behind and above the water traps could be carried out in the best possible way, so that the most accurate results were retrieved. The figure below illustrates the experimental set-up for the laboratory test.

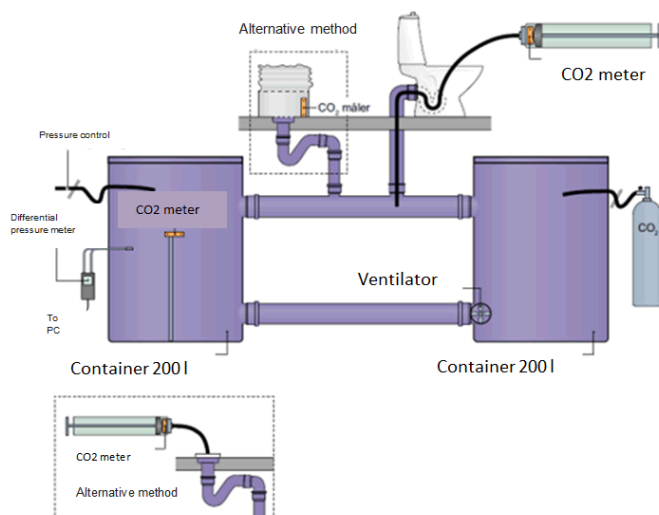


Figure 2: Experimental set-up for the laboratory test.

The laboratory tests showed that sampling behind the water trap with a tube through the water trap was an appropriate and accurate method.

The experiments with measurements above the water traps varied and gave different results, depending on the leaks (convective intrusion of air from sewer to indoor air). The tests also showed that if there was a leak, and therefore the possibility of convective intrusion of air from the sewer system to the indoor air, contamination (measured as CO₂) would spread through the water trap. If the water trap was airtight, the water in the water trap could be forced out during sampling, resulting in an open intrusion pathway for contamination of the indoor air. On the basis of the laboratory tests above the water traps it was assessed that the measurements could be used to estimate if there was a leak in the water trap.

Furthermore, the laboratory testing showed that even small leaks in the water traps could lead to convective intrusion of air from the sewer system to the indoor air.

Phase 3: Field tests at three different sites. After conducting the laboratory tests, field tests were performed on 3 different locations. The purpose of the field tests was to test the sampling procedures developed during the laboratory testing. A specific objective was to determine what happens to the concentration levels behind the water trap during sampling, and on that basis choose the right sampling volume to ensure a minimal disturbance. Furthermore, another objective was to identify the difference in sampling from a vented and a non-vented sewer system. The field tests were completed on the 3 following sites: *Location 1*: Three-story building. (Basement to 1. floor). Vented sewer system. *Location 2*: Two single family homes. Non-vented sewer system. *Location 3*: Student apartment (One floor). Non-vented sewer system.

At each location, the following measurements were conducted:

- Differential pressure between indoor air and sewer system during sampling.
- Active sampling behind water trap. Sample volume 5, 10 and 20 liters of air.
- Active sampling behind water trap with 1 l/minutes during a 100 minutes period, sample and simultaneous withdrawal of 5 liters of air after 15, 35, 55, 75 and 95 minutes.
- Active sampling above water trap. Sample volume 2 and 5 liters of air.

On figure 3-5 a selection of results from the sampling during the field test on location 1 is presented.

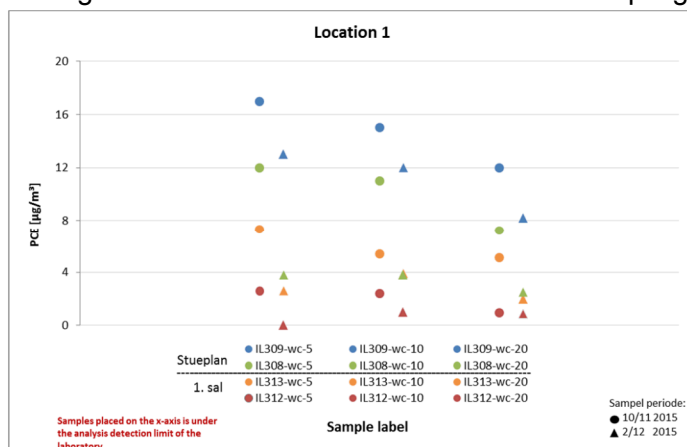


Figure 3: Active measurements behind water traps. Sample volume 5, 10 and 20 liters of air.

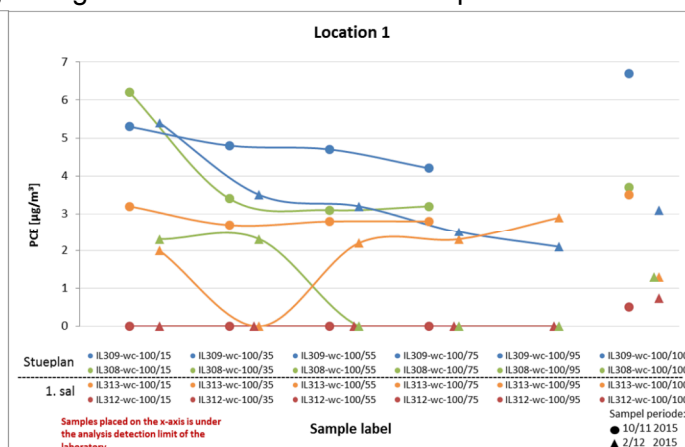


Figure 4: Active measurements behind water traps. Withdrawal of 100 liter sample and simultaneous withdrawal of 5 liters of air after 15, 35, 55, 75 and 95 minutes.

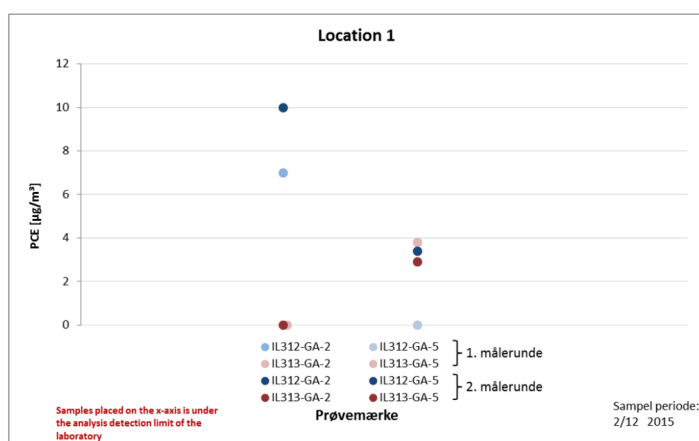


Figure 5: Active measurements above water traps. Sample volume 2 and 5 liters of air.

Based on the field tests it could be concluded that the contaminant concentrations (air concentrations) in the sewer system were affected during the sampling period. This could either be due to dilution (vented sewer system), when uncontaminated outdoor air was drawn into the sewer system during sampling or due to increasing contaminant concentrations (non-vented sewer system), when contaminated soil gas was drawn into the sewer system during sampling. Therefore, it is important to investigate the sewer system before sampling, so that it can be determined if the system is vented or not. Furthermore, it is crucial to know if there are leaks in the sewer system and if the leaks are near a hotspot of contaminated soil/soil gas/ground water. Finally, it is important that the sample volume is representative for the conditions in the sewer system and neither is affected by dilution nor increasing contaminant concentrations drawn to the sewer system.

In connection with the sampling above the water traps, the method is applicable if the objective is to examine whether the water trap is airtight or not. This type of sampling is recommended when gaseous contamination behind the water traps is already detected.

In general it is recommended to use a field registration form to ensure the collection of all relevant information to evaluate the results.

Discussion

Phase 4: Recommendation of method for air measurement in sewer and above water traps.

Based on the above discussion and the conclusions, the following recommendations have been made regarding sewer measurements.

Method	Based on	Recommendation	Justification / application
Passive sampling	Existing data	Passive sampling, 14 days sampling period in sewer wells	To evaluate the intrusion pathway and to evaluate if the main sewer system is affected by contaminated soil, soil gas or groundwater.
Active sampling behind water trap	Existing data, laboratory and field test	10 liter sample volume air. Active sampling 1 l/m.	To evaluate the potential of intrusion from the house sewer system to the indoor air, including the concentration levels.
Active sampling above water trap	Existing data, laboratory and field test	5 liter sample volume. Active sampling 1 l/m.	To evaluate if the water trap is airtight. Use when the active sampling behind water traps shows evidence of contamination.
Active sampling of indoor air as reference sample	Existing data, laboratory and field test	Not recommended	Use passive sampling of indoor air instead.

References

Lies Vanhoutteghem. 2015. Laboratorieforsøg med luftprøveudtagning fra faldstamme og over gulvafløb. Sag nr. 843-00343. Statens Byggeforskningsinstitut.

NEW POSSIBILITIES TO ASSESS RISK OF EXPOSURE IN INDOOR CLIMATES

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Background

Often when assessing risk of exposure to VOC's in indoor climates, sampling of indoor air is executed in the basement or ground floor. This is based on a crude conceptual model where gases evaporate from contaminated groundwater and enter buildings through basement floors, slabs, etc. However, several investigations in recent years have shown that the sewage system often works as a very important pathway for vapor intrusion, with a potential to affect areas several hundred meters away, or why not several stories up in a building?

During 2008 - 2012, investigations were conducted at a former dry-cleaner in northern Sweden. As a part of the health risk assessment, indoor climate was examined. Elevated concentrations of CVOC's were found in the basement, which led to a one hour restriction at the basement floor. No restrictions were implemented on the 1st floor, where much lower concentrations were detected. No measurements were conducted on the 2nd floor.

In 2015 NIRAS investigated the sewage system in a tracer experiment, which revealed that gas was leaking from the sewer into several spaces in the basement (garage), 1st and 2nd floor (office spaces). Subsequently, an extensive air sampling was performed and the results showed that the highest CVOC concentrations were observed on the 2nd floor and the CVOC composition was identical with that in the sewage, thereby indicating a connection.

The investigations have also shown that CVOC's have spread several hundred meters off site through sewer pipes, where they can potentially be a risk for the indoor climate in buildings. Also in the off-site buildings the highest CVOC concentrations are found at the top floors.

Aim

The aim of this presentation is to spread knowledge of how the sewage system can affect indoor climate, acting as a "highway" for VOC's to enter a household, and also to highlight methods to investigate this transportation.

Conclusion

This presentation may be relevant to administrative personnel (national regional etc.), consultants, entrepreneurs and others stakeholders, giving them a valuable insight into a very important pathway for VOC's.

CFD Simulation of Passive Compartment Ventilation to avoid Vapor Intrusion

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Background

When dealing with contaminated sites where indoor climate is exposed to vapor intrusion (VI), previous experience from numerous sites have shown that creating a uniform and robust passive wind driven vented sub-slab construction can be challenging.

In a co-operation between the Capital Region of Denmark and COWI, a newly developed principle for venting sub-slab constructions has been optimized in respect to Computational Fluid Dynamics simulations (CFD). CFD can be used for analyzing flow simulation of liquids and gases as well as thermal calculations. The simulations have been used to determine air resistance, laminar and turbulent flow profiles, flow rates, counter-pressure and responses to evaluate uniform venting.

One of the main advantages of using CFD simulation is to achieve significant savings on prototypes and laboratory tests. A large number of variations can subsequent implementation be evaluated and optimized.

Aim

CFD simulations has been used for the final design of a vented sub-slab construction. A preliminary geometrically model was build based on the restrictions of actually being able to apply the complete venting system on a site-specific building.

Afterwards, the preliminary geometry is changed step vice to evaluate the ongoing results focusing on minimizing pressure losses, optimizing uniform venting in the compartment and establishing a slightly depressurized compartment.

The final optimized geometrically design is going to be established on a site-specific building in November 2015. Afterwards, intensive monitoring on the ventilation performance and the concentration of VOC's contaminants in the indoor climate is going to be carried out to document and evaluate system operation and the remediation effect.

Conclusion

The initial tests of the passive vented compartment sub-slab construction show very promising results in respect to a high level of decreasing VOCs in the indoor climate. A full overview of the results obtained, the design-principles, and lessons learned will be presented at the conference in September 2016. The results can be of great value for numerous other VI-sites, where passive wind driven ventilation is a possible remedy.

Notes

Handwriting practice lines consisting of 25 horizontal dotted lines.

Session I

State of the Art - Risk Assessment

Future proofing contamination risks - *Matthew Pannett, Ramboll, United Kingdom*

Variations in bioavailability and risk of hydrophobic organic contaminants between anthropogenic impacted vs. pristine environments – *Hans Peter Arp, Norwegian Geotechnical Institute, Norway*

Categorizing the robustness of risk assessments at contaminated sites to climate changes –
Sandra Roost, Orbicon, Denmark

FUTURE PROOFING CONTAMINATION RISKS

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Abstract

Businesses have a significant role in the management and regeneration of land affected by contamination and pollution. In addition to ensuring that land is assessed and remediated to standards required by legislation, investors often wish to 'future proof' and add value to their assets and investments. Future proofing is not just an academic exercise; it is an important factor in business making decisions. This is seen in Europe and the US where many investors are choosing, for example, to assess or remediate sites beyond the minimum regulatory standards, mindful of potential future environmental risks.

This paper illustrates the concept of 'future proofing' by firstly discussing 'easy wins' and then three key topics (climate change, policy & legislation, and evolving scientific understanding). A case study is presented for each topic to show how change is happening now, to illustrate potential future land contamination risks and provide a real life example of how a 'future risk' has affected a business transaction.

Easy Wins

A first and easy step to reduce potential future contamination risks is communication. In the simplest form this includes complete and robust documentation that is carried forward with a site so that future investors know the site's contamination status and how to manage it (a surprising amount of properties have 'lost' reports or remediation systems have not been maintained, only to become an issue when the site is next sold in, say, 5 to 10 years' time).

A very well known example from the UK is a case involving bromide and bromate contamination which led to substantial pollution of a drinking water aquifer. Arguably, the pollution arose due to an action by a house builder that demolished the site and left it 'uncovered' for over two years allowing the contamination to be mobilised by rainfall. Better communication of the risks at the outset may have avoided this pollution incident.

Climate Change

Climate change could cause a remediation scheme to fail or make the assumptions of a risk assessment invalid due to changing environmental conditions. For example, climate change could cause hydrogeological and geochemical changes, such as fluctuations in water tables, flow rates, changes in temperature or dissolved oxygen and unanticipated geochemical reactions. Increased flooding and coastal erosion could also expose previously 'safe' or remediated ground contamination.

A Current Climate Change Case Study

Lyme Regis, UK

A landslide recently occurred in Lyme Regis on the southern coast of the UK. This landslide has been described as the worst in over 100 years and it exposed an old landfill that closed in the 1970s. Subsequently waste and toxic substances were found on the coast line, which is a World Heritage Site. Heavy metals have also been detected in molluscs and attributed to this incident. In little more than a generation a landfill that was once 'safely' located has become a significant contamination issue.

An Example of Future Climate Change Risks

San Francisco, USA

In the San Francisco area it has been estimated that over 100 contaminated sites could be adversely affected by sea level rises and inundation due to climate change. Research has identified possible bypassing of ground remediation barriers (such as permeable reactive barriers) due to changes in groundwater levels, and reduction in dissolved oxygen affecting microbial activity and natural attenuation of contaminants.

How Climate Change has Affected a Business Decision

Hampshire, UK

Redevelopment of a substantially contaminated site in southern England has been held up due to the expense of having to install a sea wall to a sufficient height in order to defend climate change sea level rises. The development scheme's viability was questioned due to the costs of building the sea wall and decontaminating the ground, which are fundamentally linked.

Future Changes in Scientific Understanding

Recent advances in the scientific understanding of chemicals in the environment have led to more conservative risk assessments. This may bring sites that were once thought of as safe and risk free back to the attention of the regulators as new information on harmful effects of contaminants are understood.

A Current Case Study of Evolving Scientific Understanding: Perfluorooctanoic Acid

Earlier in 2016, the USEPA published a drinking water advisory for perfluorooctanoic acid (PFOA). The new guideline for drinking water (0.07µg/l) is based on health effects information for non cancer and cancer effects, also from 2016. Previously, a provisionally guideline was issued in 2009 of 0.4µg/l. This demonstrates how a remediation or risk assessment could become invalid due to the advancement of scientific understanding and changing 'target' concentrations.

Future Scientific Risks – What is the New Asbestos?

Future risks are likely to revolve around low concentrations of contaminants that have low acute toxicity but where chronic harmful effects have yet to be fully understood. Potential cumulative effects, transformations or chemical reactions is another area that is not currently well understood.

There is evidence from the UK that risk adverse investors are adopting ever more clean building policies and prohibiting the use of certain metals and compounds due to perceived risks, and beyond that demanded by regulators. Recycled materials including waste products from other industries, whilst sustainable and currently considered safe, may become a risk in the future if not fully understood. Cumulative effects may also be an issue in terms of mixing of recycled materials.

How a Change in Science Adversely Affected a Property Transaction

Chelmsford, UK

An office developed on a site polluted by trichloroethene (TCE) was considered safe by a standard risk assessment undertaken in 2006. The review and re-evaluation of TCE toxicity by the USEPA (from which the UK takes much of its science) in 2011 meant that when the office was marketed for sale in 2015 the basis of the risk assessment was questioned leading to a delay in the sale of the property, a potential price reduction, and the expense of further assessments. The market for the property was also limited by the new guidance as risk adverse investors were more wary of the development due to the new science.

Policy and Regulation Changes

Changes in policy and regulations have the potential to alter how a contaminated or remediated site is viewed by businesses, and whether it is a safe investment. This could result from Government policy changes on how land contamination is assessed, or new regulations such as the Industrial Emissions Directive (IED).

Recent changes were brought about in the UK through a 2014 review by the UK Department for Environment, Farming and Rural Affairs (DEFRA) which led to the re-assessment of lead and other contaminants. The new assessment found that “safe” levels of lead in soils were now much lower and this was partly based on a policy decision by the UK Government.

Current Case Study - Policy

London, UK

As part of housing redevelopment, lead contamination was identified in soil planned for new gardens. The initial assessments in 2013 did not identify the lead concentrations as a risk based on the standards at the time. The DEFRA 2014 review changed the criteria for lead and the gardens were no longer ‘fit for purpose’ and had to be remediated (although the actual lead concentrations in soil had not changed).

Conversely, the UK Government has also adopted, in 2014, a more pragmatic “low risk” approach to contamination rather than the previous “minimal” risk (a policy rather than scientific decision). Some risk adverse businesses have made the decision to use the older minimal risk approach and consequently a higher standard of remediation, due to perceptions of risk. For example, a minimum risk criteria for benzo(a)pyrene is <1mg/kg and the new low risk guideline is 5mg/kg (for a residential garden).

Current Case Study – Regulation

Hertfordshire, UK

In the UK the Water Supply (Water Quality) Regulations 2000 contributes to the implementation of the Water Framework Directive. Changes to the Water Supply (Water Quality) Regulations (2000), effective from 2003, introduced bromate as a new parameter. As part of preliminary sampling and testing ahead of the new regulations a water company in southern England detected bromate and subsequently removed groundwater from its public supply. The bromate was traced back to a housing development (as mentioned earlier in this paper) and the developer and previous site owner have been found responsible and are liable for remediation costs (some reports suggesting £16m). The pollution discovery occurred more than 10 years after the site was developed and considered safe at the time, and remediation is ongoing.

Future Changes in Policy or Regulations

Examples of policy and regulations are given below that are not necessarily specific to land contamination but could have a material effect on how sites are remediated and assessed for risks.

- ‘Brexit’ is a very topical example of ‘future’ risks to businesses. One view is that, to mitigate short term financial effects of Brexit, lower environmental standards would be adopted by the UK to maximise competitiveness. Conversely, the UK may also choose a relationship with the EU in the medium to long term that keeps all or the majority of EU environmental legislation. A remediation scheme or risk assessment would therefore need to be conscious of all possible future outcomes.
- EU Directive 2014/95/EU (disclosure of non-financial and diversity information) is due for implementation from 1 January 2017. This includes the reporting of a non-financial statement to contain details on current and foreseeable risks and impacts of a business on environmental issues. The level of investor interest and requirement for enhanced transparency in reporting is likely to increase the spotlight on environmental standards and how companies are meeting these in their approaches to land contamination and risk assessments, potentially driving up remediation standards in the future.
- The Circular Economy package, adopted by the EU in 2015, has actions over the next two decades on reducing landfilling and avoiding soil and water pollution. This too has implications for how remediation schemes can be implemented and whether they will be compliant with the circular economy in the long term.
- There are EU directives on air, waste and water, but currently not soil (having been withdrawn). Will there be a “soil framework directive” in the future? Many risk assessments and remediation projects focus on soil pollution in terms of human health and groundwater. Future EU directives may see the need for remediation to consider impacts on nature, natural soil resources and a wealth of other benefits that soil provides, not currently considered by standard contamination risk assessments. This could, for example, adversely affect remediation measures that rely solely on generally inexpensive capping systems (‘land sealing’) that could easily be at odds to a future soil policies.

How Policy and Regulation Changes have affected a Business Decision

Dartford, UK

In order to prepare a site for sale, a business owner made a conscious decision to pre-remediate a site to background contaminant levels (with the IED in mind) even though there was no baseline survey. The business driver was to provide an unquestionably ‘clean’ site beyond the requirement of the regulator. This created an uplift in the value of the site and also enabled a quick sale. An additional benefit was to ensure that long term future liabilities were mitigated as far as possible by going beyond ‘just enough’ regulatory remediation.

Discussion

Businesses have recognised that contaminated land risks can evolve and perceptions of risk can change over time. An appreciation of the drivers of future land contamination risks will help businesses in taking steps to future proof contaminated and remediated sites thereby avoiding remediation being undermined, environmental risk assessments being invalidated and ultimately costing businesses more.

Variations in bioavailability and risk of hydrophobic organic contaminants between anthropogenic impacted vs. pristine environments

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Abstract

Regulatory guidelines for soils and sediments contaminated with hydrophobic organic contaminants (HOCs) like PAHs and PCBs are generally based on benchmark total soil and sediment concentrations, and not based on the more relevant concentration that is bioavailable. Risk assessments of anthropogenic impacted soil and sediment sites are in particular problematic when they do not account for bioavailability. Bioavailability is most commonly defined as the concentration currently available for partitioning with organisms, which can be expressed as the *equilibrium* freely-dissolved (pore) water concentration and measured using passive sampling. Impacted soils and sediments contain man-made particles like soots, coal tar and microplastics, which can affect the bioavailability of HOCs differently than naturally occurring particles like minerals and humic acids in pristine soils can. Thus, there is a disconnect in the relationship between total and bioavailable concentrations at different types of sites. Nevertheless, total concentration benchmarks for pristine soils remain orthodoxy for environmental researchers, regulators and consultants. Incorporating bioavailability in risk assessments can increase both the accuracy and the robustness of risk assessment guidelines across different types of locations, leading to more effective remediation approaches and more efficient usage of limited resources.

Introduction

Risk assessments of soils and sediments contaminated with Hydrophobic Organic Contaminants (HOCs) are generally based on benchmark total soil concentrations (C_{soil}) or sediment concentrations (C_{sediment}). This measurement is favored because it is intuitive, being based on the straightforward though problematic assumption that the higher these concentrations are, the greater the environmental risk. However, the bulk of research done on contaminated soils and sediments over the past two decades has increasingly shown that this assumption does not apply across diverse sites. Soil or sediment properties, and in particular the ability of a soil or sediment to bind or sorb contaminants, can affect how much of the contaminant can transfer from the soil to organisms (Brand et al. 2013) within the local ecosystem. (Note for the rest of this article soil will be used to refer to soil and sediment, unless otherwise specified.)

One soil property, however, that is commonly included in risk assessments to account for sorption is the mass fraction of total organic carbon, f_{TOC} . Generally, the higher the f_{TOC} , the greater the ability of a soil to bind contaminants. However, even if f_{TOC} is accounted for, the ability of TOC to sorb HOCs can vary strongly in different contaminated areas. In a pristine area, the organic matter present would be dominated by naturally occurring soil organic matter (SOM). However, in areas impacted by anthropogenic activities, such as gasworks, coke ovens, wood impregnation sites, urban areas, and urban harbors, which are typically the areas where risk assessments are performed, different types of carbonaceous particles may be present (soots, microplastics, tars, chars, cokes), that can substantially vary in their binding potential of HOCs. As an example, strong-sorbing carbonaceous materials, like black carbon (BC) and coal tar, can lower PAH bioavailability compared to SOM. How can we account for this variability of HOC in different types of polluted areas?

Bioavailability and its measurement with passive sampling

As an alternative to risk assessments of HOCs based on total concentrations, several researchers have argued that an improved framework should be based on bioavailability or alternatively bioaccessibility (Reichenberg and Mayer 2006, Cachada et al. 2014). Bioavailability is generally referred to as concentration *currently* available for partitioning with organisms, which based on the principle of chemical activity can be quantified by the *equilibrium* freely-dissolved concentration, C_{free} (i.e. the concentration just solvated by water) (Reichenberg and Mayer 2006). There are an increasing number of established ways to measure C_{free} using equilibrium passive samplers (EPS), which generally involve adding a strip of plastic (a passive sampler) to a soil or sediment sample in a vial, and shaking until equilibrium is reached (e.g. Arp et al. 2014). The principle of how EPS can be used to estimate C_{free} , and from there biota concentrations (C_{biota}) and lipid concentrations (C_{lipid}), is presented in Figure 1. As evident, through a combination of EPS-"free" water partition coefficients (K_{EPS}), lipid-water partition coefficients (K_{lipid}), biota concentration factors (BCF), EPS concentrations can be related to C_{free} , C_{biota} and C_{lipid} , as well as help determine soil-water partition coefficients (K_D).

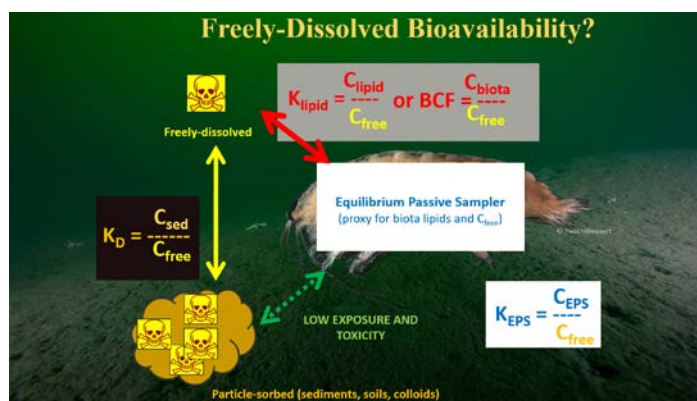


Figure 1. Principle of how EPS derived C_{free} values are related to bioavailability

By contrast, bioaccessibility is generally defined as the concentration *over some time frame* that will be available for partitioning with organisms (Cachada et al. 2014). A recent, comprehensive review has concluded that none of the current methods used to measure PAH bioavailability or bioaccessibility can account for bioaccumulation or toxicity for all types of organisms, as different organisms can have different uptake pathways, particularly plants vs invertebrates (Cachada et al. 2014); however, bioavailability seems promising for lower tier organisms like amphipods and worms, where baseline narcosis is typically the main mechanism of toxicity, as shown in Figure 2 (Arp et al. 2014).

Uptake experiment with *Enchytraeus crypticus* (4 weeks exposure)

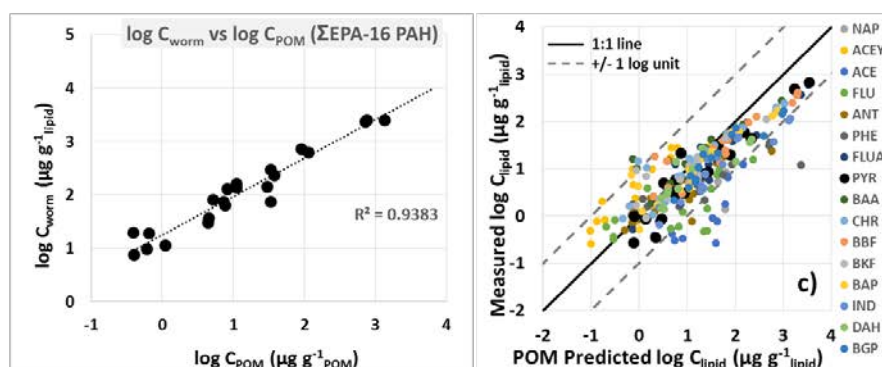


Figure 2. An example of how equilibrium passive sampler concentration (POM) can be related to uptake in lipids of the worm *E. crypticus* (Arp et al. 2014)

Why bioavailability is important to risk assessments

There are two central reasons why C_{free} is a much better quantifier of risk than total soil concentrations for risk assessment of anthropogenic impacted sites. The first is that total benchmark concentrations assume that soil K_{TOC} (soil TOC-water partitioning coefficients) are consistent for all soil types. But K_{TOC} of PAHs can be a factor of 10 -1000 more than in pristine sites, as confirmed by several other researcher as well as our own results (see Figure 3).

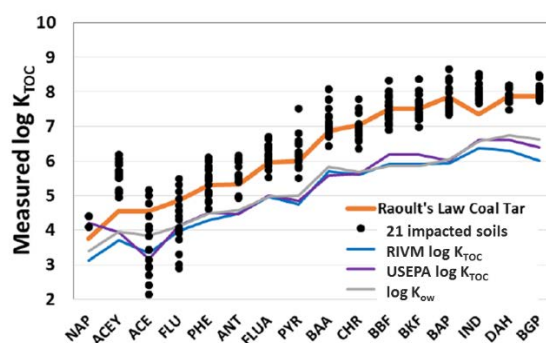


Figure 3. $\log K_{\text{TOC}}$ of PAHs measured impacted soils compared to K_{TOC} values recommended by regulators (RIVM and USEPA) (from Arp et al. 2014). The $\log K_{\text{TOC}}$ values in diverse impacted areas resembles the sorption of coal tar rather than regulatory values for pristine areas, which resemble the sorption of octanol.

The second reason to use C_{free} is that the majority of soil benchmarks (units $\mu\text{g}/\text{kg}$ soil), such as Average Annual Environmental Quality Standards (AA-EQS), are based on aquatic benchmarks (units $\mu\text{g}/\text{L}$), which are extrapolated using these problematic K_{TOC} values.

$$\text{AA-EQS}_{\text{sediment/soil}} (\mu\text{g}/\text{kg}) = \text{AA-EQS}_{\text{water}} (\mu\text{g}/\text{L}) * K_{\text{TOC}}/f_{\text{TOC}} \quad (1)$$

Thus, the benchmarks themselves are problematic for impacted sites and associated with a lot of uncertainty. In general use of soil benchmarks derived with K_{TOC} for pristine sites are extremely conservative when applied to anthropogenic impacted soils, as shown in Figure 3, and could potentially lead to a waste of resources in terms of clean up and remediation costs.

Possible solutions to account for bioavailability in a risk assessment framework

We can contrast two extremes for strategies to account for bioavailability in risk assessment frameworks: radically via a Tier 1 approach, and more cautiously via a Tier 3 approach.

The radical, direct Tier 1 approach would be to simply forego all sediment and soil benchmarks, and just take C_{free} values in the units of water (e.g. $\mu\text{g/L}$) and compare them to water quality benchmarks, like AA-EQS_{water} ($\mu\text{g/L}$) (note that aqueous concentrations are generally the same as C_{free} ($\mu\text{g/L}$) if sorption to dissolved and colloidal particles is insignificant). The basic assumptions here is that soil and sediment toxicity tests would not be needed, as aqueous concentration benchmarks for aquatic ecosystems, as expressed as C_{free} , would be the same for soils and sediments. There is a solid, theoretical sound basis for this, and that is the aforementioned principle of chemical activity, which by extension indicates that C_{free} is the maximum exposure concentration any given organism can be exposed to, indirectly, at a given time. This approach would be a radical change from most existing guidelines, but if adopted, one would also have the option of basing guidelines on reference passive sampler concentrations, or alternatively reference biota/lipid concentrations.

The more cautious Tier 3 approach has been suggested by Brand et al (2013) among others, and is easier to incorporate into existing guidelines: one first determines if the total soil or sediment concentration is enough to warrant further assessment (Tier 1), followed by an assessment if there is a need to determine an urgency or remediation action plan (Tier 2). Following this, at Tier 3, regulators and site managers should be open to revising their risk assessment based on bioavailability, especially if resources are limited, as areas where C_{free} are above aquatic benchmark values, or are the highest, is where most remediation activities should be focused.

Future Perspectives

Bioavailability and emissions are truer measures of risk at contaminated sites than total soil or sediment concentrations. Further, EPS measurements are analytically cheaper, require less resources (solvents), and are overall more consistent than soil and sediment measurements. There are an increasing number of standardized EPS lab methods and labs that measure C_{free} . Thus, the quantification procedures are firmly in place to integrate them in standardized risk assessment. The biggest frontier now is the development of *in situ* tools that can assess bioavailability directly in the field, without disturbing the soil. In addition, through strategic placement of *in situ* EPS, this data could be integrated into transport and emission mapping of actual bioavailable C_{free} concentrations in contaminated sites. Risk guidelines and assessments should continue to allow for alternatives of being based on bioavailability, rather than total concentrations, to allow for the the most effective use of resources during risk assessment and follow-up action.

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CATEGORIZING THE ROBUSTNESS OF RISK ASSESSMENTS AT CONTAMINATED SITES TO CLIMATE CHANGES

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Abstract

This project comprised of data collection and a nationwide screening that included data on contaminants, typologies (site geology) and critical climate elements. The results of the nationwide screening were subsequently verified by a local analysis in two municipalities. This, to evaluate the performance of the nationwide screening as well as to give recommendations for improving the nationwide screening and identify data needs for a more local scale analysis.

The project included contaminated sites in areas with specific drinking water interests (OSD) and / or within the catchment areas for public water supply, as well as contaminated sites that pose a risk to surface water bodies. Two matrices of risk indicators were developed by combining the model substances and their properties with typologies and the critical climate elements.

The most important climate elements with regards to contaminant migration and increased leaching of soil contamination were identified. Climate changes include increased precipitation, which results in a rise of the groundwater table and increased groundwater recharge, higher sea levels, increasing temperatures, and finally stronger and more frequent extreme events. In addition to climate changes, man-made measures such as drains, sewers and utility lines were considered.

Introduction

Today, risk assessment of contaminated sites as performed by the Danish regions is based on the current climate conditions. It is unknown to what extent changes in climate will affect the robustness of the risk assessments carried out. This project has elucidated the extent of the problem, as well as developed and tested a framework for categorizing the robustness of the risk assessments on registered contaminated sites in Denmark as high, fair or low with regard to climate change effects.

The project is part of a three-step process for identify the contaminated sites, which pose a risk to groundwater or surface water bodies, for which climate changes are estimated to affect the robustness of the original risk assessment. Step 1 is a nationwide screening, which includes existing national data from the national databases. Step 2 is a more local scale analysis in which site-specific data are included and interpreted. Step 3 is a detailed analysis that includes a local scale model with information on hydrogeology, contaminant transport and climate scenarios. The project only covers the first two steps of the planned 3-step process.

Materials and Methods

The nationwide screening is based on a wide range of existing data in the national registers. To begin with, all registered contaminated sites in Denmark are included. Based on a conceptual understanding of contaminant transport, three types of sites (typologies) were defined with variations in geology, hydrogeology and migration pathways. Each contaminated site was assigned one out of ten possible model substances with associated characteristics in terms of mobility, degradation, and occurrence depth (m bgs) for the three typologies.

Based on a range of climate changes, the most important climate elements with regards to migration and increased leaching of soil contamination were identified. Climate changes include increased precipitation, which results in a rise of the groundwater table and increased groundwater recharge, higher sea levels, increasing temperatures, and finally stronger and more frequent extreme events. The following climate elements were selected as the most significant:

- Increased groundwater recharge that results in increased contaminant leaching
- Raised groundwater table that results in increased contaminant leaching, change of drain conditions, moistening of dry pockets and thus contaminant mobilization, changing redox conditions, changes in end-receptor and / or changes in flow rates and directions.
- Local flooding which can cause increased contaminant leaching or increase the surface runoff of contaminants.
- Flooding along streams and lakes, which can cause increased contaminant leaching or increase the surface runoff of contaminants.
- Rise in seawater levels/flooding which can cause increased contaminant leaching or increase the surface runoff of contaminants. In this project only sudden rises due to storm surges are included

In addition to climate changes, man-made measures such as drains, sewers and utility lines were considered. Climate adaptation measures such as LAR (local drainage of rainwater) are also included in the robustness analysis. Infiltration of more rainwater in connection with LAR projects can cause a rise in the groundwater level and thus result in increased contaminant leaching as mentioned above.

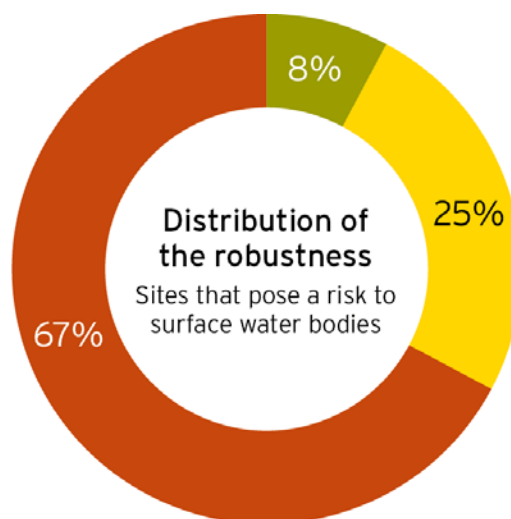
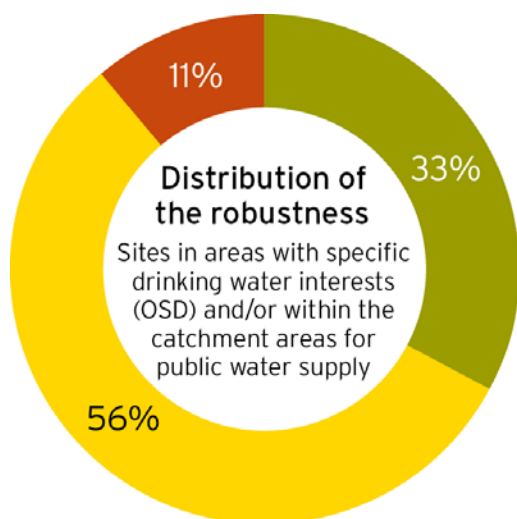
We developed two matrices of risk indicators by combining the model substances and their properties with typologies and the significant climate elements. One matrix relates to contaminated sites that pose a risk to groundwater, while the other matrix relates to sites that pose a threat to surface waters. By combining the above parameters, the risk indicators represent the robustness of the current risk assessment to changes in climate conditions.

Results

The nationwide screening included approximately 32,000 sites registered as contaminated or possibly contaminated. Almost 12,000 are registered as posing a potential threat to groundwater while 3,000 sites are registered as posing a potential threat to surface water.

The remaining sites are located outside zones of groundwater interest or surface water risk zones. However, these sites were also included in the initial steps of the screening in order to assess the overall scale of the task of evaluating at how many sites the current risk assessment would be affected by climate changes.

The result of the nationwide screening is showed in the figure below. It should be noted that the delineation of the nationwide screening for surface waters only included sites that have previously been assessed to pose an actual threat, while for groundwater, the screening included any site inside a zone of groundwater interest/abstraction, regardless of the actual risk.



■ 3.831 - High robustness of the risk assessments
■ 6.539 - Medium robustness of the risk assessments
■ 1.352 - Low robustness of the risk assessments

■ 273 - High robustness of the risk assessments
■ 841 - Medium robustness of the risk assessments
■ 2.216 - Low robustness of the risk assessments

Increased groundwater recharge is the only climate element that affects the risk assessment for groundwater sites to such an extent that the robustness is categorized as low. For sites that pose a risk to surface water climate adaptation projects (LAR) are the most critical climate element. In addition, flooding along streams as well as floods from rising sea level result in a low robustness of the original risk assessments.

An objective of the project was to test the nationwide screening on a local scale at two municipalities (Kolding and Greve). The purpose of the test was to evaluate whether the nationwide screening of the robustness was comprehensive, and specifically whether the used data and input parameters were adequate and accurate.

Overall, there is good agreement between the nationwide screening results and the results achieved in the local scale test. The assumed typologies, model compounds, and their properties were found adequate to represent site conditions when taking into account screening purposes. In some cases, we found that the model compounds were more mobile than the actual contaminants. This underestimates the robustness of the original risk assessment and therefore provides a more conservative result.

The climate elements that were tested at local scale included increased groundwater recharge, elevated groundwater table and LAR (climate adaptation measures) in the municipalities. It was not possible to identify suitable sites to test the remaining climate elements. The local scale verification of the nationwide screening for the above three climate elements showed that the results of the screening gave a true and fair view of the expected robustness.

Based on the results from the nationwide screening and the local scale test in the two municipalities, there was given recommendations for improving the nationwide screening and to identify data needs

for the more local analysis. The aim is to build the foundation for an improved and finalised nationwide screening tool.

Discussion

In general, there was a good agreement between the assumptions, input parameters and results of the nationwide screening and the analysis of local data. Therefore, we conclude that the performed nationwide screening gives a reliable picture of the robustness of risk assessment in relation to groundwater and / or surface water risk, as well as to the extent of the expected task.

The success criterion for the first specific objective was to ensure that the collection of existing data included all relevant data and that the quality was sufficient to perform a nationwide screening. This was fulfilled as a test of the nationwide screening at local scale showed that the amount and quality of data were adequate.

For the second specific objective, the success criterion was to give a general estimate of the number of sites in which the current risk assessment would be affected by climate change, as well as sort out at least 20% of the potential sites nationwide, as sites with a high robustness of the risk assessment. The project succeeded in developing GIS themes and risk matrices that were included in the screening and provided a nationwide overview. The nationwide screening showed that with the initial assumptions and input data, it was possible to categorize 34% of the registered sites as sites with a highly robust risk assessment.

The third specific objective was to test the nationwide screening at two smaller areas and on this basis to make recommendations for improvement of the screening in step 1, and recommendations for more detailed analysis in steps 2 and 3. It has been possible to meet the success criteria for the validation of the nationwide screening. It has also been possible to give an assessment of how the input data in step 1 can be improved as well as what data that needs to be used as input in steps 2 and 3.

As part of the fourth specific objective recommendation for improving the nationwide screening (step 1) and partly the more localized analysis (step 2) and a detail analysis (step 3) are given as to input parameters (model substances, typologies and climate elements).

This project, which has been defined as a pilot project, has identified several issues in which further work could be performed. This is e.g. development of a final categorization tool that can automate the nationwide screening (step 1). This tool could be dynamic tool, in order to allow an update of the input parameters if, for example new climate models become available, or the need for new model substances or climate elements arises. In addition, it should be possible to directly integrate the tool in a step 2 local scale analysis.

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Notes

Handwriting practice lines consisting of 20 sets of horizontal dotted lines.

Session J

Methods for site studies - PART II

Comparison study of different methods for estimation of mass discharge in aquifers -
Nina Tuxen, Capital Region, Denmark

Interactive 3D-tool for better communication in contaminated soil remediation projects - *Håkan
Rosqvist, Tyréns, Sweden*

Effective use of geostatistical tools - how to optimize target volumes for contaminant source
reduction - *Niels Doessing Overheu, Capital Region, Denmark*

Long sediment cores from the Helsinki sea area diminish previous estimates of contamination -
Arto Itkonen, FCG, Finland

COMPARISON STUDY OF DIFFERENT METHODS FOR ESTIMATION OF MASS DISCHARGE IN AQUIFERS

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Abstract

Four different methods to determine the contaminant mass discharge downgradient of a site contaminated with chlorinated solvents were tested and compared. The methods included the “traditional” transect method (with measurements of concentration, hydraulic gradient and hydraulic conductivity), the “Point Velocity Probe” (PVP) combined with concentration measurements and the two passive devices: the “Fluxsampler” and the “Passive Flux Meter” (PFM). The different methods were tested for their performance on determining groundwater flow direction, the Darcy flux and the contaminant mass discharge. The tests were done at a well-characterized site, where solid information on the site conceptual model existed up front.

Introduction

Today, most risk assessments of contamination in the groundwater from point sources are based on mass discharge assessments. The mass discharge is a combination of concentration and ground water flow, thus revealing the actual contaminant mass leaving a site. Mass discharge estimates are normally done in a downgradient transect intersecting the contamination plume. Here measurements of concentration, hydraulic gradient and hydraulic conductivity are combined to give the mass discharge. Since determination of the hydraulic parameters can be particularly difficult, several methods have been developed to measure the Darcy flux and/or the contaminant mass discharge more directly, i.e., without reference to Darcy's Law. With several available methods on the market, there is a need for testing and comparing the methods, in order to establish the technologies' relative strengths and weaknesses, and to explore opportunities for using the technologies in a complimentary fashion.

Materials and Methods

The investigation was carried out on the Østergade transect at the Skuldelev site – a site with an extensive groundwater contamination by PCE, TCE, and their chlorinated degradation by-products. The transect was studied previously and is described in several published investigations. Thus, the geology, the hydrogeology, and the groundwater contamination are very well known. The results of this project support the earlier evaluations in determinations of the overall flow direction, and hydraulic gradient. Furthermore, the groundwater contaminant concentrations generally remained stable within the timeframe of this investigation. These factors made it possible to realize a prerequisite for the project, which was to focus the investigations on the core of the plume, where the contribution to total contaminant flux was dominant.

The traditional method of measuring contaminant mass discharge involves the hydrogeologic characterization to quantify the flow system to determine the specific discharge across the transect. At this site, slug tests were performed to establish hydraulic conductivity and well soundings were conducted to calculate hydraulic gradients. In addition, groundwater samples were collected from wells and multilevel samplers and analyzed to establish contaminant distributions in the aquifer. A mass discharge is obtained by multiplying the concentration by the Darcy flux.

The Point Velocity Probe (PVP) is a small device installed in direct contact with the aquifer material. It has three injection ports located 120° apart on the probe surface, where a small amount of salt solution can be released. Between the injection ports, pairs of detectors are installed. Tracer breakthrough curves at any of the detector pairs can be used to calculate the ambient groundwater velocity (magnitude and direction).

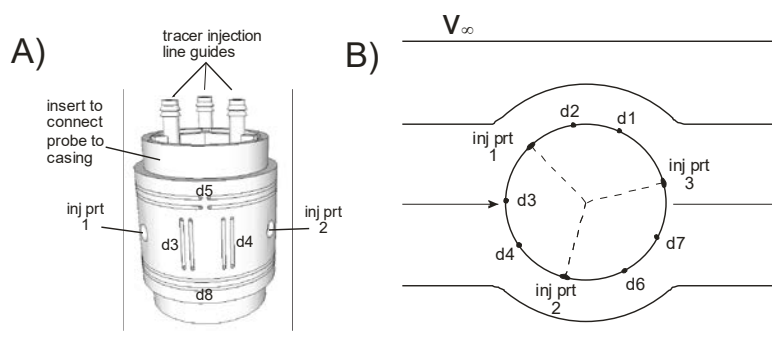


Figure 1. A) Schematic of a PVP /1/.

The two passive technologies, the Fluxsampler by Sorbisense and the Passive Flux Meter (PFM) developed at University of Florida, are based on the same principles. Both devices are installed in wells and groundwater flows through them without any pumping. Each contains a sorbent, that retains the contaminants that pass through the samplers with the flowing water, and a tracer that is simultaneously leached from the device by the groundwater. Thus, these devices permit the measurement of both the contaminant mass discharge through a well (from the amount of contaminant sorbed over the time of the test) as well as the Darcy flux (from the tracer disappearance). Furthermore, the Fluxsampler is divided into 3 separate chambers that can provide insights into general flow direction by triangular vector geometry. In the current project, a similar 3 chamber concept was tested in the PFM.

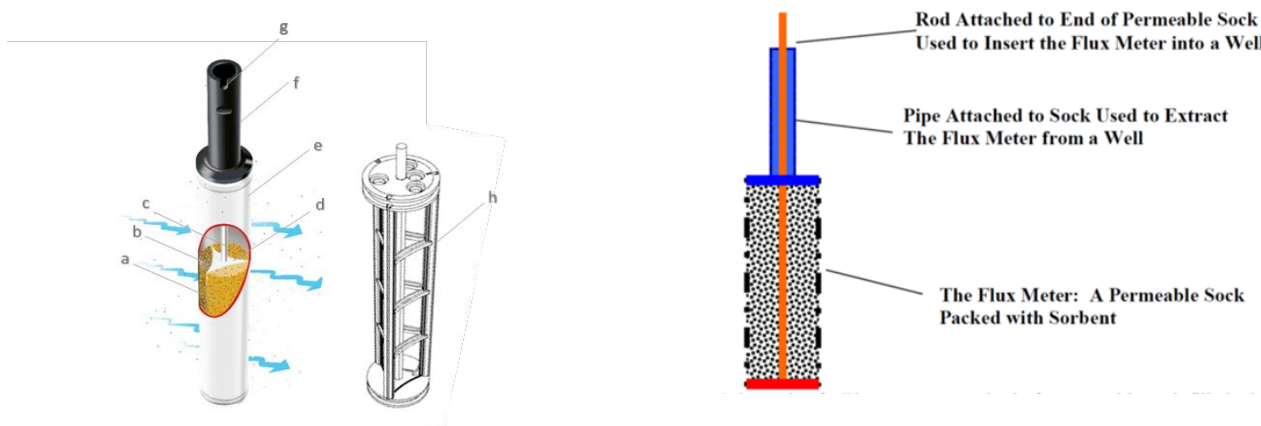


Figure 2. Left: Schematic of a Fluxsampler /2/, right: Schematic of a PFM /3/.

Results and discussion

The different methods were tested for their performance on determining groundwater flow direction, the Darcy flux and the contaminant mass discharge.

Groundwater flow direction. The passive samplers produced flow directions that were highly variable, with differences up to 90°, and various possibilities for improvement were identified. In contrast, the PVPs indicated flow directions with better consistency and agreement with the direction estimated from hydraulic gradients (results not shown).

Darcy flux. The traditional and indirect determination of Darcy fluxes yielded the lowest Darcy fluxes, while the highest results were obtained from the Fluxsampler (Figure 3). Overall, it was found that the four methods, with only a few exceptions, provided comparable results, i.e., within a factor of 5. In one of the PVP measurements, a very high value was obtained. However, two previous measurements in the same PVP at an earlier stage had values in the order of 0,01 m/day. The reason for this temporal variation has not been determined. Results of parallel tests of shorter duration (2 weeks) with the Fluxsampler indicated that the higher Darcy fluxes determined by the Fluxsampler compared to the other methods might in part be explained by differences in the dissolution rates of the tracer.

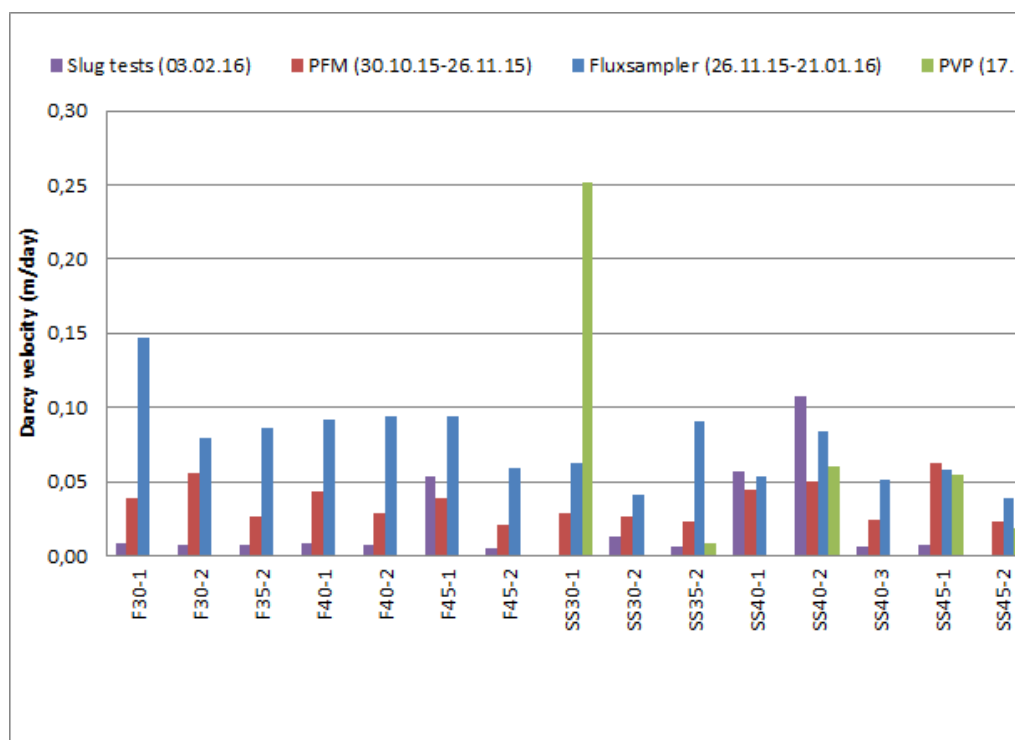


Figure 3. Darcy velocity estimated by four different methods. The dates mentioned are when the sampling periods were.

Contaminant mass flux and mass discharge. The results of the project show that the contaminant mass fluxes measured by the Fluxsamplers are generally comparable to the PFM results (Figure 4). Based on the estimated values of the mass flux and the Darcy fluxes, the flux averaged concentration can be calculated and compared with the measured groundwater concentrations. With the exception of vinyl chloride, the flux averaged concentrations determined by the Fluxsampler and the PFM are generally below the concentrations measured in the groundwater, and the PCE and TCE results for the Fluxsampler are below the estimated flux average concentrations determined by PFM (results not

shown). This is a direct result of the calculations that used higher Darcy velocity estimates from the Fluxsampler and lower values from the PFM.

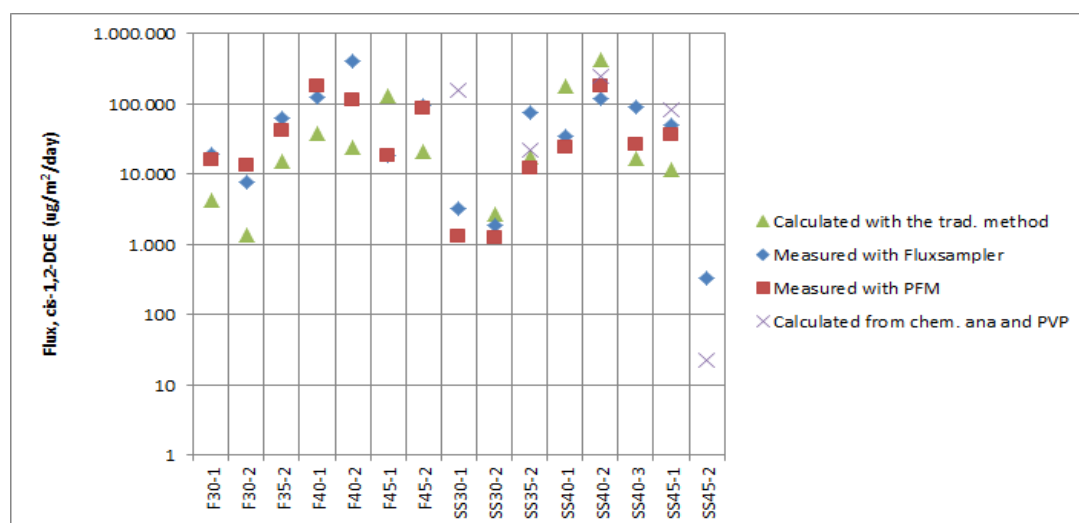


Figure 4. Measured and calculated mass flux for cis-1,2-DCE determined with the four different methods

The mass discharge across the entire transect was estimated by dividing the total area into several constituent rectangular cells. A total of 9 different approaches for estimating mass discharge were then then applied to each cell and totaled to obtain a total mass discharge for the transect. The results were then compared. The 9 methods included 3 based on the traditional method using hydraulic conductivity, hydraulic gradient, and groundwater concentrations measured in water samples from wells and multilevel samplers, 2 based on the results of the PVP measurements combined with concentrations in water samples, 2 based on the results of the PFM measurements, and finally 2 based on the results from the Fluxsampler. The 9 different methods generally yielded similar mass discharge estimates (0-1.5 kg / year for PCE, 0-0.8 kg TCE / year, 1.1-3.4 kg cis-1,2-DCE / year, and 0.2-1.2 kg vinyl chloride / year). There were, however, significant variations within each rectangular cell.

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INTERACTIVE 3D-TOOL FOR BETTER COMMUNICATION IN CONTAMINATED SOIL REMEDIATION PROJECTS

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Abstract

The methodology presented in this paper seeks to improve the basis for communication between different stakeholders in soil remediation projects. The aim is also to improve the conditions for better processes leading to more efficient and cost effective remediation of contaminated land. Typical stakeholders are problem owners, contractors, consultants, researchers, media and the public. The GeoBIM concept was developed for geo-projects relating to subsurface infrastructure. 3D-visualization of sub-surface environments based on digital models developed in GeoBIM can be extracted, exchanged or networked to support decision-making. In this paper, we present how different types of geo-related information can be combined and communicated for better understanding of subsurface conditions leading to more effective soil remediation projects. In our paper we show results of extensive investigations from a site contaminated with Dense Non Aqueous Phase Liquids (DNAPLs) in southern Sweden.

Introduction

Better understanding of spatial and temporal distribution of subsurface contaminants before, during and after actions for remediation is of great importance. An important factor for more efficient decision processes in projects is the possibility for good communication between different stakeholders at different stages of the soil remediation process. The GeoBIM concept has been developed in our project inspired by the concept of Building Information Modeling (BIM). BIM is a process involving the generation and management of digital representations of physical and functional characteristics in buildings and other assets.

The aim of our project is to show how different types of geo-related information can be combined and used for better understanding of subsurface conditions, thus leading to more effective communication in projects concerning soil contamination and remediation. The main point of this paper lies on the importance of effective visualization for a better communication. In this paper, we present results from investigations at a site contaminated with DNAPLs in Kristianstad, Sweden. DNAPLs, such as chlorinated solvents, are common pollutants steaming from among others, dry cleaning facilities and other types of industries. They are especially problematic as they are denser than water and migrate down through the groundwater, not always following the groundwater flow due to the gravitational forces. Difficulties associated with remediation activities of DNAPLs are especially delineation of the source plume, and understanding of the migration of contaminated groundwater in the underground.

Materials and Methods

The contaminants, chlorinated solvents, comes from a former dry cleaning facility (Kv Färgaren, Kristianstad, Sweden), that was in operation from 1906 until 1988. Due to the location near the largest national ground water resource in Sweden, the Kristianstad plains, in combination with the potential of contamination, the site is classified as one of the high-risk sites in southern Sweden identified in a national environmental risk assessment inventory. The site has therefore been listed for remediation subsidy from the government where the municipality of Kristianstad is the principal of the remediation

project. During 2016 the remediation project started by initial actions preparing for an in situ Thermal Conduction Heating campaign. The investigated site is located on the northeastern fringe of a light industrial neighborhood, zoned as a future residential area in Kristianstad, Sweden. To the east is a UNESCO protected wetland and river situated. In Figure 1, the location of the site is shown.



Figure 1. The site of the old dry cleaning facility (encircled by the dashed yellow line), with sampling points visible as white dots.

Over the last decade, the combination of direct current resistivity and time domain induced polarization (DCIP) has been developed in order to take advantage of the two methods and improve the understanding and mapping of the sub-surface situations in various applications. DCIP is based on injection of current pulses through the subsurface. The current injections are made via electrodes installed in at the ground surface along a measurement line. During the current injections, potential differences are measured at several points in a profile below the measurement line. After data processing and modelling, a profile of the distribution of resistivity and chargeability in the subsurface is obtained. Some previous electrical resistivity or DCIP studies have focused on industrial sites contaminated with chlorinated hydrocarbons (Cardarelli & Filippo 2009 and Johansson, et al., 2015).

BIM is a process involving the generation and management of digital representations of physical and functional characteristics by digital models developed in BIM that can be extracted, exchanged or networked to support decision-making regarding a building or other built asset. BIM software is used to plan, design, construct, operate and maintain diverse physical infrastructures, such as water, wastewater, electricity, roads, bridges, etc. Over the last few years, the GeoBIM concept was developed in a research project relating to subsurface infrastructure, such as tunnel construction (<http://trust-geoinfra.se/delprojekt/4-1/index.html>). The database is the central feature in the concept and various applications can be developed from the database, such as, general information, design, drawings, modelling and visualization (Fig. 2).

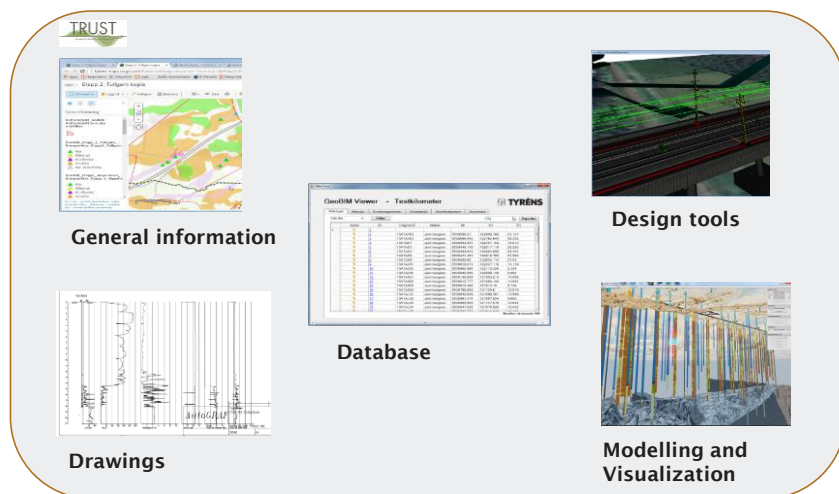


Figure 2. GeoBIM - a concept for different aspects of data management including design, modelling, visualization, storing and maintenance for geo-related projects.

To visualize and analyze acquired data, we use Golden Software's Voxler® software. Voxler can handle diverse raw data formats (e.g. csv, xls, dxf, tif, grd) and allow for combined visualization and 2D and 3D analysis of these. In this study, we have collated, streamlined and imported downhole borelogs (xls), laser derived topographic models and orthoimages (tif), AutoCAD drawing files (dxf) and xyz-point cloud data (contaminant concentrations and geophysical data; xls). Predefined import templates allow for easy and fast display. Still in Voxler, selected data have been subject to gridding, interpolation and graphical processing to create 3D models of e.g. contaminant extent and geological formations.

Results

The understanding of basic geological structures is important for an overall understanding of conditions for the spatial distribution and potential migration of contaminants. Figure 3a shows borehole logs where the extent of different types of soil and rock have been registered, and in Figure 3b, the interpolated and interpreted geological boundary is shown. That is, the boundary between clay and sandy till.

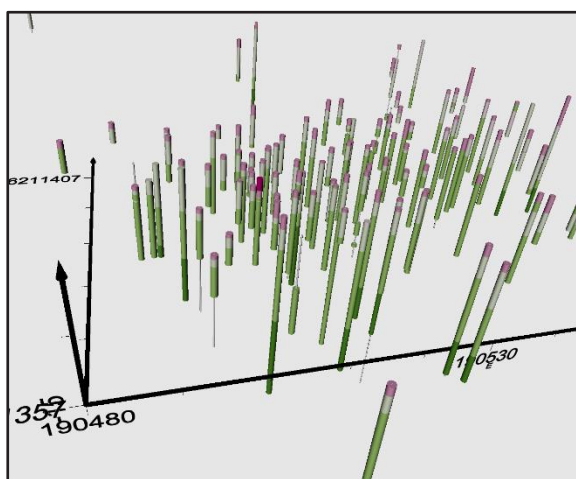


Figure 3a. Borehole logs. Different colors display different soil/rock types

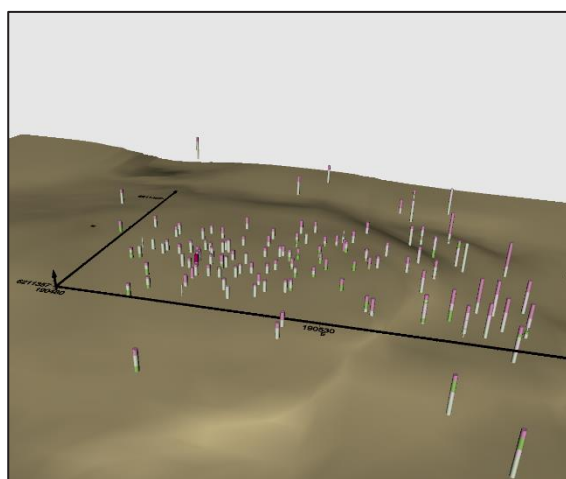


Figure 3b. Boreholes with an interpolated geological boundary based on the well log data.

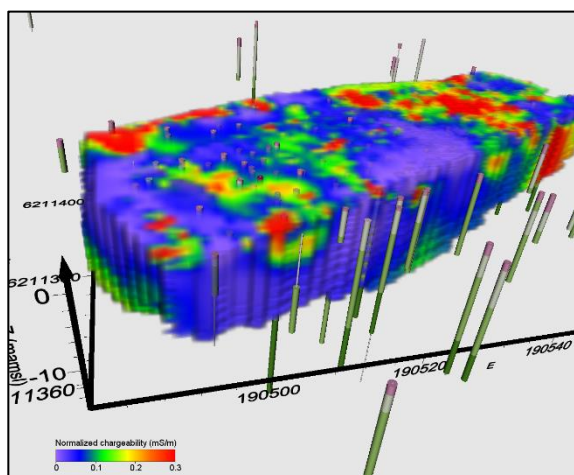


Figure 4a. Normalized IP data in relation to the boreholes.

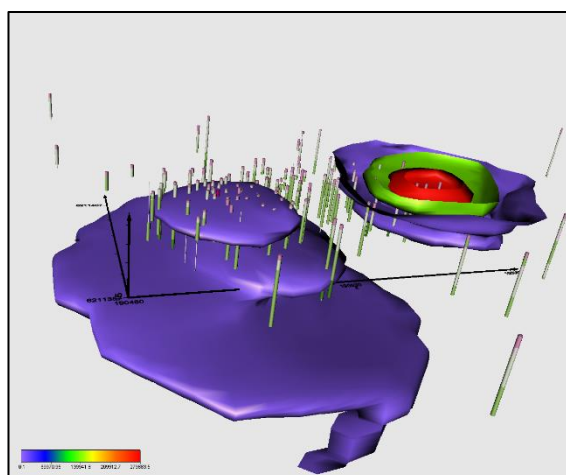


Figure 4b. Vertical view of interpolated isosurfaces of PCE in groundwater. Different colors denote different concentrations.

Figure 4a shows results of DCIP measurements designed for 3D-interpretation. Zones indicated in yellow and red show higher values of normalized IP. In some areas, the results indicate possible occurrence of chlorinated solvents, whereas in other areas the high normalized IP values indicate organic fraction in the soil, i.e., zones with peat. In Figure 4b interpolated results of groundwater samples are shown, where blue/purple indicate low concentrations and red, high concentrations. Preliminary results show that interpolated data indicate a match with the DCIP results.

Discussion

Combination of different geo-related information, such as, soil and groundwater samples, geophysical surveys, and sub-surface constructions result in highly complex situations. Better understanding of sub-surface condition based on good visualization therefore support the decision-making processes in soil remediation projects. The methodology for 3D interpretation and visualization that has been developed in our project give support to more effective methods for better understanding of the conditions and improvement of communication between stakeholders in a remediation project.

For a better understanding, it is concluded that the combination of different types of information is important. Moreover, to present data in 3D for a better spatial understanding of the conditions is crucial, and possibilities for interactive presentations further enhance the understanding of sub-surface conditions. Our results show that the use of DCIP can increase the understanding of the distribution and migration of chlorinated solvents contaminations.

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EFFECTIVE USE OF GEOSTATISTICAL TOOLS - HOW TO OPTIMIZE TARGET VOLUMES FOR CONTAMINANT SOURCE REDUCTION

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Abstract

Remediating a contaminated site is expensive work, particularly if the contamination is far below the ground surface or in others ways is difficult to reach. So it is economically sound to remediate only the volume that poses a risk. And how do we define that? Our understanding of the subsurface always relies on interpretation of discrete point data and we must accept that our estimates involve uncertainties. These uncertainties can be difficult to grasp and quantify, but they are vital if we want to give a reliable estimate of risk and target volumes, rather than just our best guess. And there are tools to help us visualize and understand the uncertainties without extra workload.

We can reduce uncertainty by investigating more, but this is also costly business, and how do we know when we have investigated enough? Could a few more data points narrow down our target volume and decrease the overall cost – or are extra data points redundant? Our study shows that geostatistical modeling is an effective tool to answer these questions and to set up operational remediation targets that honors the uncertainties of the contaminant distribution.

Introduction

The five regions in Denmark are responsible for the task of mapping, investigating and remediating the orphan contaminated sites in Denmark. The task is huge, and the regions work closely with research institutions and private companies to develop better, cheaper and more sustainable methods to solve this task. One of the angles in this work is to improve our assessments of how much remediation is needed to reduce the risk to an acceptable level.

Our understanding of geology and contaminant distribution at contaminated sites will always rely on interpretation, interpolation and - to some degree - on guesswork. However, if we can improve our knowledge on the target volume for contaminant source removal, we can reap the benefits of minimizing the costs and the risk of project management trouble.

A few years back the CRD undertook a thermal remediation project that turned into an economic and managerial challenge when more contamination was found during the establishment of the heating system. This late discovery necessitated an expansion of the heating area, causing large unforeseen expenses. This case and other experiences has led the CRD to change its practice on contaminant source characterization – we aim to strengthen data discipline and describe the source volume in much more detail before deciding on the remediation strategy and signing with a contractor.

But how do we know when we have collected enough data? And how do we process that information to define a target volume that reduces the risk to acceptable levels?

Materials and Methods

Together with the consultant DMR, the CRD has tested how we can use a geostatistical tool (in this case Kartotrak by Geovariances) to organize the data collected at a site, to define target volumes for source removal and to evaluate the benefit of conducting additional site investigations.

The tool was tested on data from a heavily TCE-contaminated site, which currently faces expensive remediation. The site is well characterized after multiple site investigations with more than 100 boreholes and 1,100 soil samples. The investigation history allowed us to conduct the analysis after different investigation phases and evaluate the benefit gained from acquiring extra data points.

The study was carried out in a free-form manner based on a wish-list written by the region to see how far we could get with the data and software at hand. The purpose was to extract general experiences with geostatistical modeling that can be used in future projects. The wish-list included:

- Visualization of contaminant mass and related uncertainties in the soil volume
- Assessment of target volumes as combinations of TCE concentration and the wanted certainty to remove different concentration levels
- Is it preferable to conduct comprehensible or separate calculations at sites with several hot spots?
- Analysis of data from different investigation phases – were the extra data points placed appropriately to reduce uncertainty and can the tool give better guidance on this?
- Did the expenses of extra data points pay off by reducing the target volumes?
- How much data is needed at a site for geostatistical modeling to make sense?

In brief, the geostatistical modeling was carried out in the following steps

1. Organization and quality control of geologic and contaminant data in a database
2. Analysis of data sets and calculation of variograms to describe the spatial continuity
3. Calculation of average values – or “best guess” – of TCE distribution
4. Conditional simulation of 100 possible distributions for each investigation phase
5. Geostatistical analysis of the realized distributions and calculation of uncertainties related to mass and volumes
6. Assessment of changes in uncertainty from one investigation phase to the next
7. Extraction of perspectives and recommendations

The modeling work was carried out by DMR with sub-consulting service by the software developer Geovariances.

Results

Geostatistical modeling allows us to not only see the average spatial distribution gained through traditional kriging methods, but also to gain insights into the uncertainties related to the spatial distribution and use them actively in the target volume definitions. For example, we may wish to remove high concentrations of a compound with 95% confidence, since we need to be almost 100% sure to remove the high concentration volumes. For lower concentrations we may settle with lower confidence levels. Examples of such volume calculations are shown in figure 1 below. It is easy to test the effect on target volumes of different concentration and confidence levels, and this is a great tool for cost/benefit assessments.

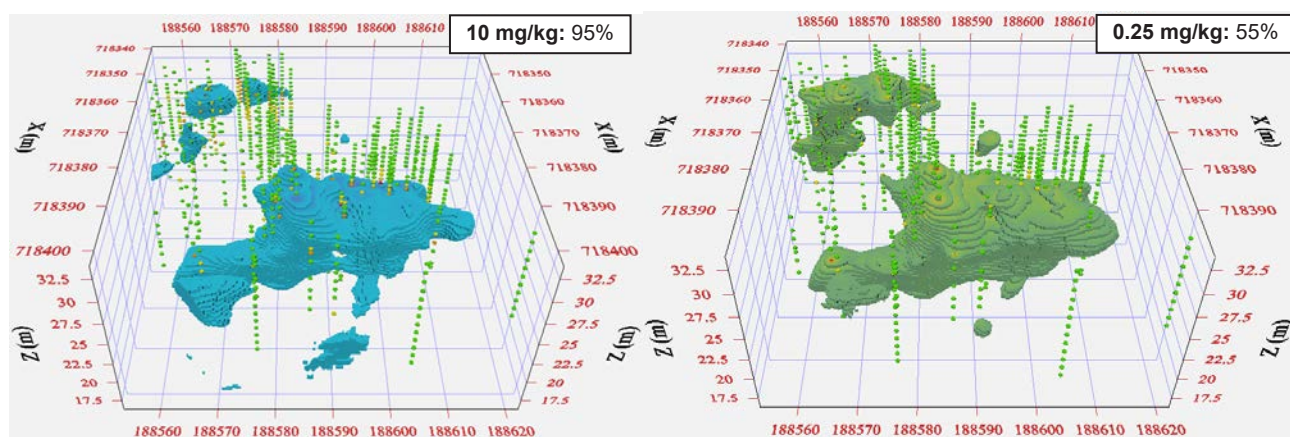


Figure 1. Example of calculated target volumes for different concentration- and confidence levels. In this example, we may wish to define a target volume that is the sum of the two volumes.

The tool can also be used to help us locate areas where additional sampling points would benefit a reduction in the uncertainties - and help us more accurately assess the soil volumes requiring remediation. Figure 2 shows an example of how additional sampling may reduce uncertain volumes. Less uncertain volume means a reduction in the target volume to be remediated.

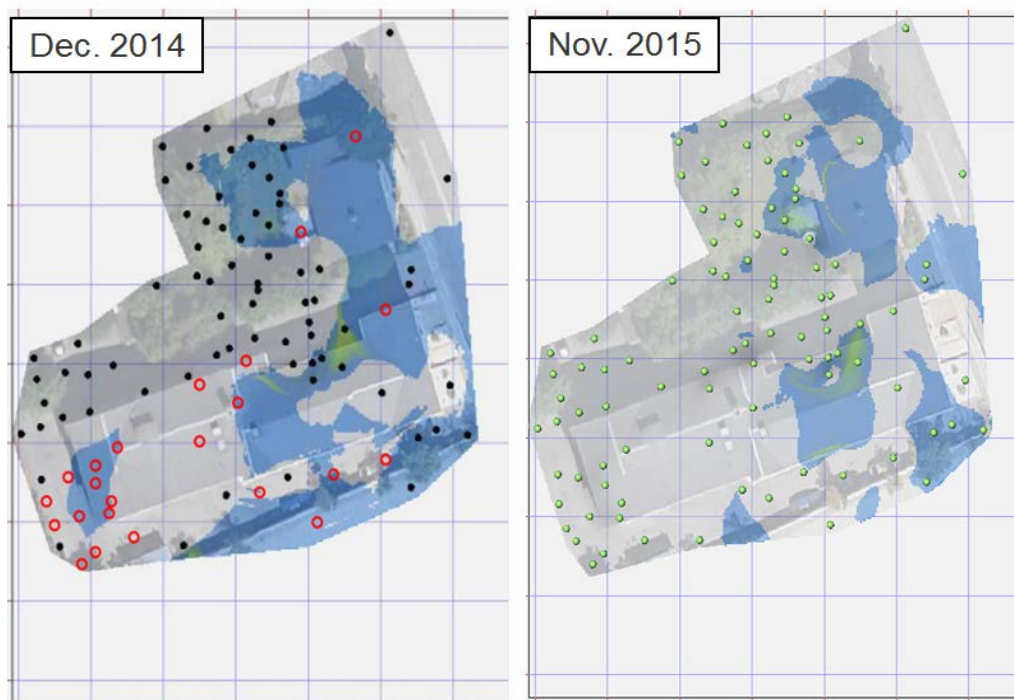


Figure 2. Plan view of uncertain volumes (blue areas) after each of the two major investigation phases in the case study. Black dots are the data points in the 2014 survey and the red dots are additional data points in the 2015 survey. It is clear that the additional data points have reduced the uncertain volume (i.e. less blue area in the 2015 figure).

Discussion

Geostatistical tools can support our work by providing a platform for easy overview and analysis of data as well as a systematic and intuitive way to work with the uncertainties in our projects.

We expect geostatistical tools to have a wide range of uses to optimize our efforts on both comprehensive site investigations and remediation projects. This first test indicates that the right time to roll out the “geostatistical guns” is when the investigations show, that a site is a possible candidate for remediation or monitoring. We currently consider how we can systematically incorporate geostatistical principles when offering CRD projects for tender in the future.

We have tested a number of uses, like systematic definition of target volumes and the benefits of additional investigations, but there are more uses to explore. Examples include

- “What-if”-scenarios – e.g. if we drill three more boreholes and they are clean (as predicted by the model), how much will our target volume decrease? And what is the return of investment on the extra survey, compared to the reduced remediation volume?
- Calculations on the risk of the remaining contamination outside the target volume and coupling of mass estimates with remediation criteria.

These examples will be topics of our continued studies on the use of geostatistical tools.

As a final word we want share what was an eyeopener for those of us, who have just recently started working with geostatistics. This is the fact that traditional interpolation methods (like kriging) smoothes out data and does not take the actual data variability into account. This means that interpolated data should not be used to determine the soil volume that exceeds a certain threshold value. The conditional simulation used in geostatistics re-introduces the actual variability, giving a much better estimate of the actual conditions. The presentation will include an example of this.

LONG SEDIMENT CORES FROM THE HELSINKI SEA AREA DIMINISH PREVIOUS ESTIMATES OF CONTAMINATION

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Abstract

City of Helsinki is developing its shore areas, which means large scale dredging and filling works. The topmost sediments are contaminated. Estimation of the volumes of contamination is significant both in terms of money and time spent on remediation. Adoption of a new sampling method, Kullenberg piston coring, has enabled accurate and reliable estimation of the depth of the contaminated layer. The results were first compared with previous estimates at the Sompasaari sea area in 2014, and have since then been used at other areas as well to verify the previous results. It has become evident that other sampling methods may lead to significant overestimation of contamination due to lack of knowledge of the deeper stratigraphy of sediment, and/or due to sampling-generated contamination of the deeper samples by the surface sediments.

Introduction

Sampling is the most critical phase in sediment studies comprising up to 80-90 % of the total error. Problems associated with equipment used are related to slowness of the sampling, heaviness of the handling of equipment, loss of the surface sediment layer, poor sediment penetrability of the corer (limited coring depth), disturbance of the sediment core and problems in taking subsamples. Part of the uncertainty generated by sampling can be removed by acoustic profiling. However, it is clear that site-specific sampling equipment is needed and the sampling strategy has to be selected so that no systematic error is generated.

Avoiding the error generated by sampling has a large financial impact. Each year, the City of Helsinki uses hundreds of thousands of euros for the placement of dredged contaminated sediments. The expenses are largely dependent on the degree of contamination. These problems are emphasized in the updated dredging and sea placement instructions recently given by the Ministry of the Environment, Finland (Ministry of the Environment, 2015).

Materials and Methods

The Sompasaari former port area is developed for a residential use. The construction work, which started in 2015, includes new sea fills and approx. 75,000 m³ dredging up to 10 m sediment depth from an area of 28,000 m². The dredging area has been studied in 2005-2013 mainly by means of samples taken with a geotechnical sampling rig, by divers and with surface sediment gravity corers (approx. 20 sample points). In order to verify that the estimates of contamination are correct, the City of Helsinki ordered an additional sampling campaign in 2014. Altogether 13 cores were taken with a modified Kullenberg piston corer. The corer is capable of taking cores that are several meters long.

The sampling was performed by Geological Survey of Finland (GSF) and supervised by FCG Design and Engineering Ltd. (FCG). This method has not been used earlier in investigations of dredged sediments in Finland.

The Kullenberg corer is a large piston corer. Several versions exist, but the one developed by GSF can be loaded with up to 400 kg weight. The minimum water depth needed for coring is some 2-3 m, and a steady platform (e.g. a large draft or ice cover) is needed for the support tripod. Inner tubes with a diameter of 52/60 mm are used in the corer for sampling. Total length of the sample sections cored is limited mainly by water depth and penetrability of the sediments. A detailed description of the corer is presented by Putkinen and Saarelainen (1998).

Results

Length of the cores taken in 2014 from the Sompasaari sea area was between 1.35 - 4.45 m depending on the hardness of the bottom. It was not possible to take samples from two sample points that were located on hard erosion bottom. In laboratory, the tubes were cut in halves, and logged geologically. Stratigraphy of the cores was divided into the following main lithostratigraphical units by the specialists of GSF: 1) topmost loose, highly sulphide-coloured clay gyttja (at previously dredged areas replaced by sand / gravel), 2) sulphide-banded gyttja clay, 3) homogenous clay and 4) varved clay (Fig. 1). The surface of uncontaminated glacial varved clay was found at 0.65 - 2.35 m sediment depth at the eastern side and 0.1 - 1.5 m at the western side of Sompasaari (FCG, 2014).



Figure 1. Topmost part of core FCG3925 showing transition from lithostratigraphical unit 1 (loose, highly sulphide coloured clay gyttja) to 2 (sulphide banded gyttja clay). Photo: GSF.

Geochemical analyses were performed on the cores in order to verify the concentrations of pollutants. Altogether 44 samples were analyzed for loss-on-ignition, clay content, metals and PAH-, PCB-, organotin-, VOC and oil compounds. Analyses were made in SGS Inspection Services Ltd. Results verify the stratigraphy. Pollution was detected only in the topmost units (1 - 3, Fig. 2), while unit 4 was clean. Even though no dating was made, it can be interpreted that the lowest layer most probably originates from the preindustrial era. A possible erosion surface is located between units 3 and 4. According to Itkonen (2007), a significant part of the bottom area of Helsinki was erosion bottom before the large scale sea filling around and between the 19th century islands in the area. This has

changed flow patterns and started deposition of material during the last two hundred years at many places in the area.

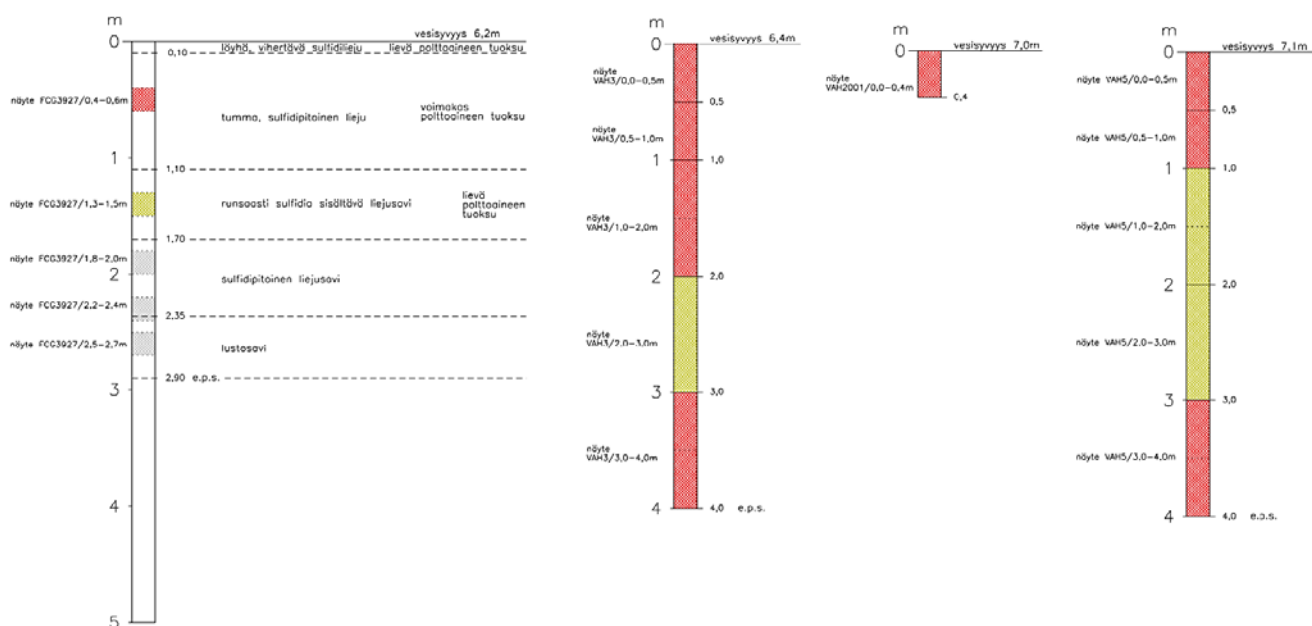


Figure 2. An example of the comparison of a Kullenberg core (left) with the previous cores taken with geotechnical coring rig and by a diver (the second core from right). Depth scale is the same in every core. Notice the large variation in the interpreted degree of contamination. Colors refer to Finnish Quality guidelines for dredged materials: red = contamination at level 2, yellow = contamination at level 1A – 1C, and grey = contamination at level 1, at the background level. FCG (2014).

Results from the Sompasaari sea area show that previous estimates exaggerate thickness of the topmost contaminated layer, probably due to mixing of the top layer with the deeper layers while sampling. In the Sompasaari area, this led to a revision of the previous estimate of 28,000 m³ to 15,000 m³ of moderately and 44,000 m³ to 15,000 m³ of heavily contaminated sediment.

Discussion

So far, most of the samples taken at the Helsinki sea area have been taken with grab corers, Russian peat corers, small piston corers, different types of gravity corers (e.g. Limnos, Kajak and Gemax), geotechnical sampling rigs, and by divers. Despite the coring rig, the penetrability of all these methods is limited to the top sediments. Thus, the whole sediment layer planned to be dredged cannot be studied. The lower surface of the contaminated layer must in many cases be interpreted based on indirect evidence. This may lead to serious miscalculation of the volumes of contaminated sediment. What is more, this study confirmed the doubt that geotechnical coring rig seriously disturbs the sediment diving contamination deeper.

The Kullenberg sampling method allows collecting long continuous sediment cores that are relatively undisturbed. In addition, the penetration ability of the corer is much better than with lighter gravity corers or corers operated by divers. With a Kullenberg corer, it is possible to do a reliable geological logging through the whole dredged layer, and focus the analysis so that degree of contamination can be unambiguously interpreted. This is a major advantage compared to previous methods.

The Kullenberg method has a few disadvantages associated with the availability of equipment, expenses, time required and water depth. However, these shortages can be overcome, and since spring 2014, the method has been utilized at several other dredging areas in the City of Helsinki. The method has proved to be worth the money spent in these areas as well.

Financial consequences of the difference in estimated volumes of contaminated sediment are significant. These estimates are used for planning the treatment, and plans are seldom changed in the dredging phase. Common unit expenses of treatment of contaminated sediment exceed 30 €/t. In the Sompasaari case, this could mean saving of some 42,000 m³ sediment from unnecessary remediation, worth more than 500,000 €. In addition, time is saved and environmental impacts are reduced when uncontaminated sediments are placed in the sea instead of tedious transportation to a treatment facility and unnecessary treatment.

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Notes

Handwriting practice lines consisting of 20 horizontal dotted lines.

SESSION K

Specific types of contaminated sites

Baseline Studies of Methane Emissions from Landfills Before Establishment of Biocovers -
Lessons Learned - Malene Front, NIRAS, Denmark

Solving the acid mine water challenge after nearly 400 years of copper mine activity at Løkken
Grube, Norway - *Arve Misund, COWI, Norway*

A new method for identifying and characterizing black shales for safe disposal: a case study from a
large construction project in Norway - *Erlend Soermo, Norwegian Geotechnical Institute, Norway*

Impact of chlorinated compounds in groundwater on streams - a study on 30+ contaminated sites
in Denmark - *Sanne Skov Nielsen, Orbicon, Denmark*

BASELINE STUDIES OF METHANE EMISSIONS FROM LANDFILLS BEFORE ESTABLISHMENT OF BIOCOVERS – LESSONS LEARNED

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Background

Landfills receiving organic waste are producing landfill gas (LFG). LFG emissions contribute significantly to the global release of anthropogenic methane causing global climate changes.

In Denmark there are 3000 old closed down landfills. With the aim of reducing emissions of methane from 100 landfills the Danish Parliament has allocated approx. 24 mio. Euros in grant funds to the establishment of biocovers including preliminary baseline studies. Biocovers are a relatively new technology which exploits microbial oxidation of methane.

Investigations of methane emissions from landfills are challenging due to the size and topography of the landfills as well as the spatial and temporal variation in methane emissions. Furthermore, there are limited experiences with characterization and quantification of methane emissions from landfills, identification and evaluation of areas suitable for biocovers and establishment of biocovers. As part of a pilot project under the Danish EPA NIRAS and the Technical University of Denmark (DTU) have performed baseline studies of methane emissions from three Danish landfills in 2015.

Aim

The aim of the baseline studies has been to quantify the total emission of methane from each of the three landfills and to identify wells and hotspot areas with significant emissions of methane suitable for establishment of biocovers. Furthermore, it has been the aim of the project to gain experience of using the results from the baseline studies as basis for decisions on the design and type of biocovers.

The baseline investigations have included quantification of the total emission of methane by use of the dynamic plume tracer dispersion method (performed by DTU) and surface screenings with a FID-instrument (performed by NIRAS).

Conclusion

With the investigation methods available and despite of a high number of measurements it has been found to be still difficult and also labor-intensive to map methane emissions from the landfills. Thus, it may be difficult to identify and decide on suitable biocover sites and to decide on the design of biocovers. Experiences suggest it may be necessary to perform flux measurements as part of the baseline studies. In order to optimize the screening process – both in relation to time consumption and accessibility of the landfills - NIRAS and DTU is developing and testing drone based methods to perform surface screenings on landfills.

Acid mine water challenge after nearly 400 years of copper mine activity at Løkken Grube, Norway

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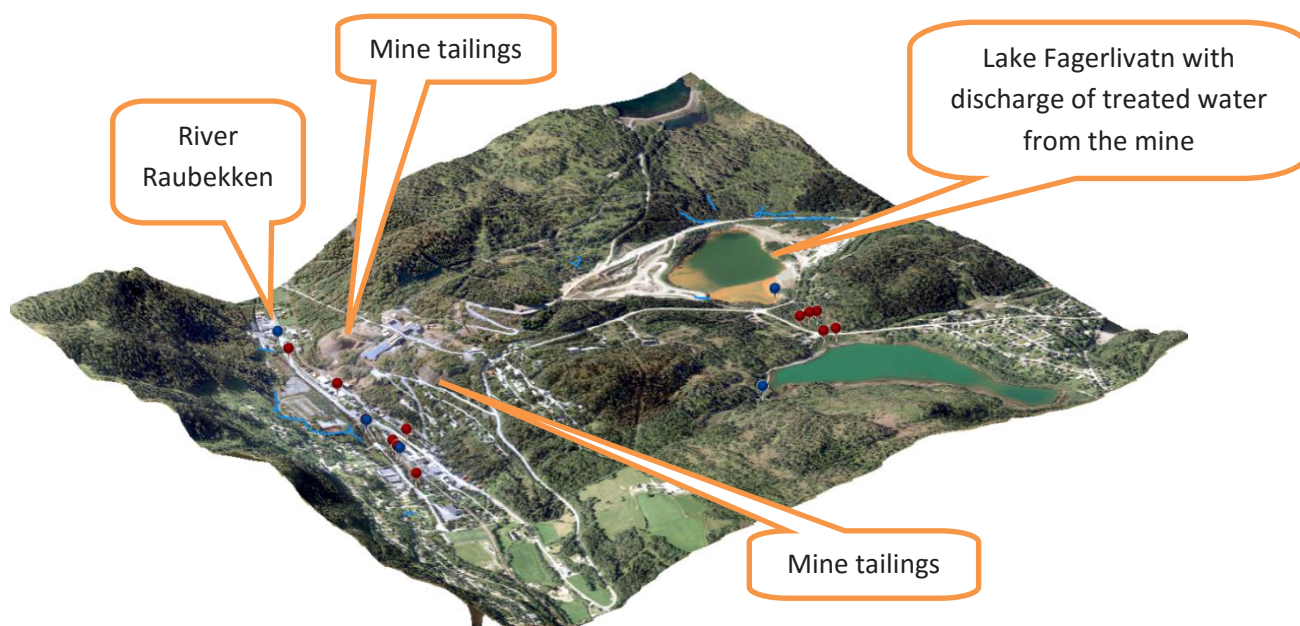
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Background

At the Løkken copper mine there has been mining activity since 1654, and it has been the most polluting pyrite mine in Norway over a long period. In Figur 1 is given an overview of the mining town. Since the 20th century, there has been an increasing focus on environmental issues at the site. Starting in 1952 with construction of a 25 km long wooden pipeline for leading acid mine water to an outlet in the closest fiord instead of the local river Raubekken. After the mine was closed in 1987 there has been taken further actions to reduce the leaching of mine water to the nearby river, Raubekken. One of the measures has been to collect acid water runoff from the mine tailings and pump it back into the mine. After closure, the mine has been reused as a treatment plant, with the effect of less acid water leaking to the local water bodies. Over the last years the effect has decreased, and it is a need for finding new solutions to deal with the acid mine water.



Figur 1: Overview of the mining town Løkken.

Objective

Investigations over the last years has revealed high concentrations of copper in river Raubekken, with average numbers of 400 µg/l. The accepted value is 175 µg/l. The aim of

this project is to find effective measures to decrease the runoff of acid mine water in order to increase the surface water quality.

Main approaches to solve the situation are:

1. Capping the mine tailings
2. Cut off trenches upstream the mine tailings
3. Making new plant for liming water pumped from the mine
4. Collection and treatment of polluted groundwater before discharge to surface water

This presentation will focus on point 4.

Methods

There has been conducted geophysical surveys to map sediment characteristics in order to get information about e.g. depth to bedrock and possible weakness zones in the bedrock. Geotechnical as well as well drillings were used to map sediment and depth to bedrock and to establish monitoring wells. The information is used to establish a 3D groundwater model to get a better understanding of the acid groundwater movement towards Raubekken and thus to find locations of collection wells.

Results

As can be seen in Figure 2, there is a change in river- and groundwater quality along the valley. There is especially one area where there is a correlation between high concentration of the groundwater and an abrupt change in surface water indicating discharge of polluted groundwater. In this area there is no visible local source of pollution and the contamination can be transported through fracture zones or unconsolidated sediments from the area with mine tailings. The reason for the discharge may be the shallowing of the aquifer and a window with coarser material (Figure 3). Because of excessive precipitation of iron there is an approximately 30 cm hard layer in the river bottom. Strong contaminated groundwater trickles up through this iron rich deposit layer.

Since the river- and groundwater has this abrupt change in water quality at one specific site, establishing a well for a pump and treat solution is under testing. An alternative method will be to collect the polluted groundwater and pump it back to the mine for treatment.

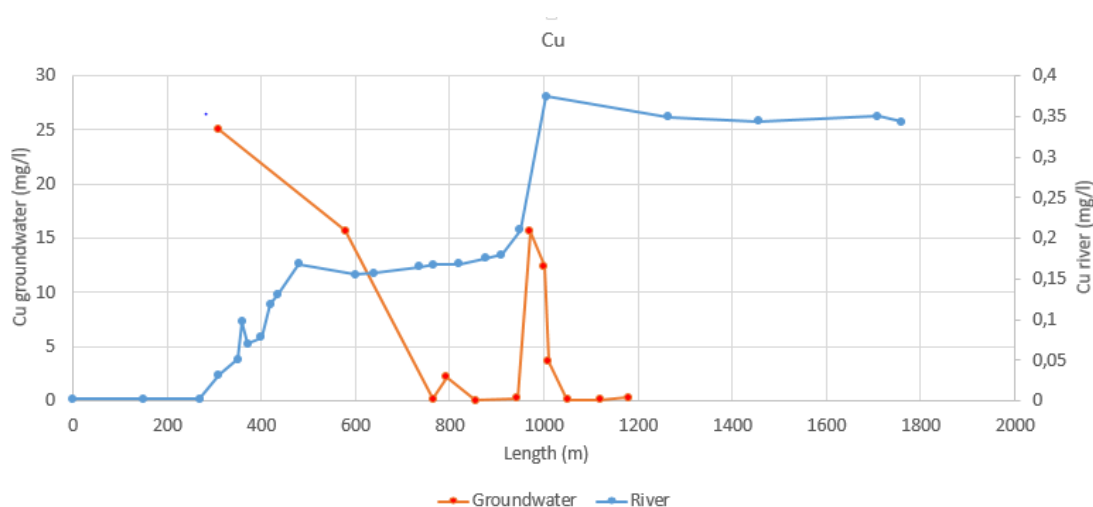
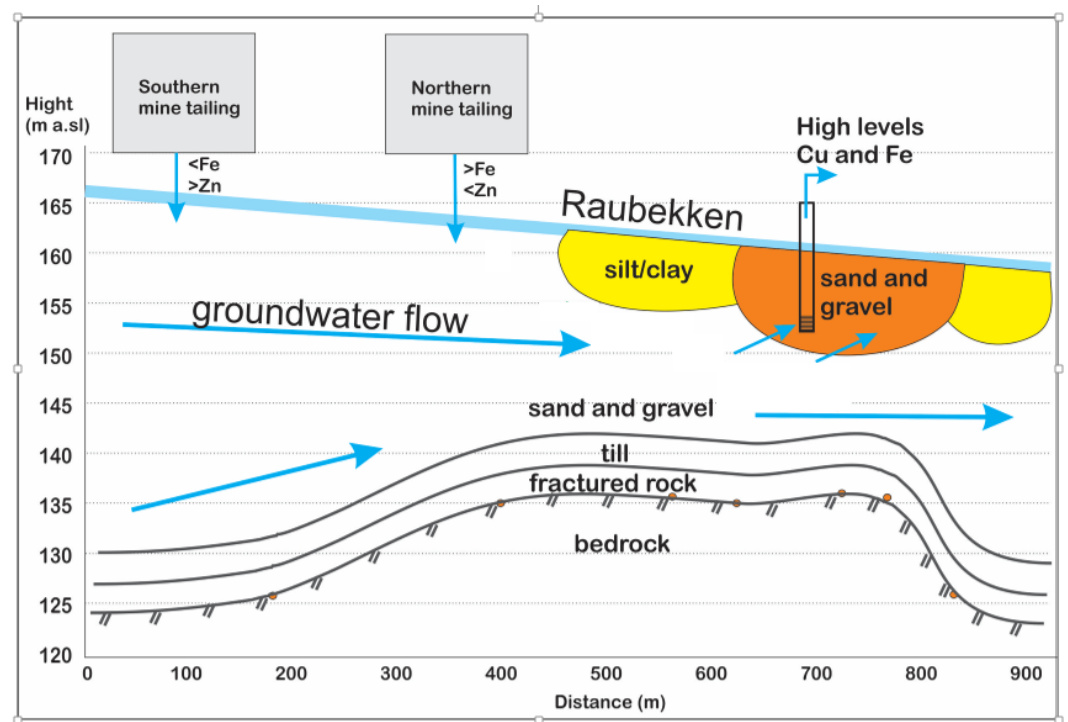
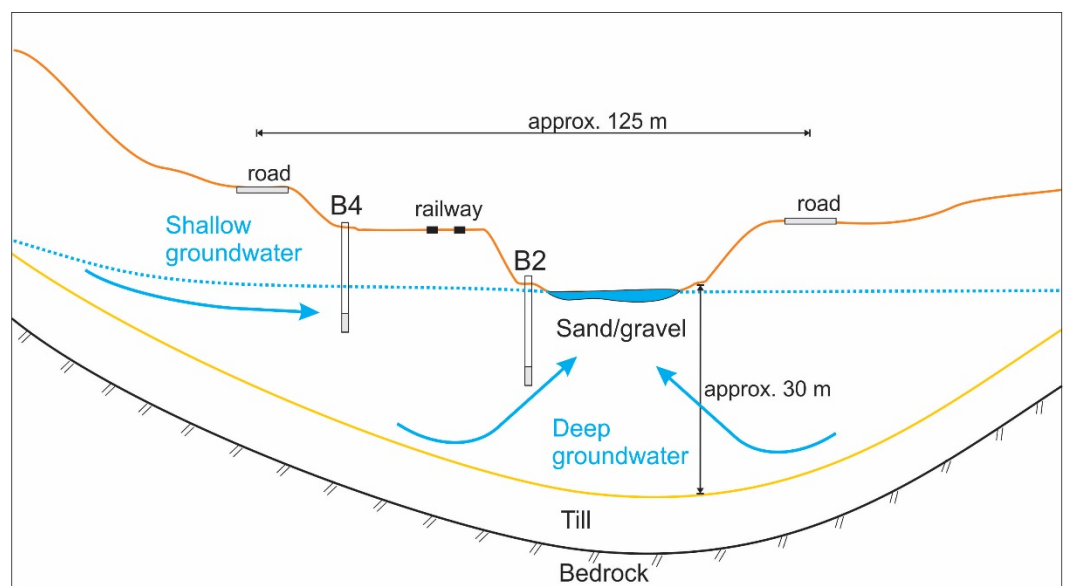


Figure 2: Copper-concentration in river- and groundwater along river Raubekken.

Length section



Cross section



Figur 3: Length- and cross section of the river Raubekken illustrating the conceptual model of the hydrogeology in the valley.

Another important aspect is to reduce the contaminated flow of groundwater due to outwash of the mine tailings. Measures will be taken including construction of cut off trenches to decrease inflow of clean water, new pipelines with better capacity installed and extensive capping of mine tailings. For capping there will be used different measures depending on the later areal use. Different options include bentonite for grass areas and asphalt for areas that will be used as parking lots.

Conclusion

Results so far shows that the groundwater transport of acid water is of vital importance in understanding the increase of copper in river Raubekken. The copper concentration rises from less than 1 µg/l upstream the mine tailings and a groundwater discharge area, to c. 400 µg/l downstream. The main pollution has been identified to 2 areas along Raubekken. It has been designed measures to collect and treat acid and copper-rich groundwater before entering Raubekken. In addition the mine tailings will be capped, and rainwater collected to prevent formation of acid draining water. Upstream the mine tailings, cut off trenches will be made in order to reduce the amount of polluted water.

A new method for identifying and characterizing black shales for safe disposal: a case study from a large construction project in Norway

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Abstract

Black shales found in the Cambro-silurian succession in Norway are enriched in sulfides, which are widely known to generate acid rock drainage (ARD) when exposed to oxygen and water. Black shales have caused repeated problems, significant costs and delays in construction projects. A new method developed by the Norwegian Geotechnical Institute (NGI) correctly places black shales in their lithological succession and characterizes their potential for developing ARD. The aforementioned method was adapted to enable the use of a portable x-ray fluorescence instrument (pXRF) for quick and efficient characterization of the rock masses in a large construction project. The results showed that the bedrock in the building pit consisted of black shale from horizons 2 and 3a, containing high concentrations of sulphur (20 000 – 60 000 mg/kg) and uranium (40 – 200 mg/kg). The adapted method allowed for the safe disposal of rock masses based on their potential to cause environmental harm and also resulted in a greatly reduced project cost.

Introduction

In Norway, the Cambro-silurian succession of sedimentary rocks contain several different horizons of black shales (Owen et al., 1990). These black shales are enriched in iron sulfides (Autun, 1967), which can react with oxygen and water to generate acid rock drainage (ARD) (e.g. Nordstrom et al., 2015). Additionally, some black shales have high concentrations of heavy metals and uranium (U) (Pabst et al., in review). The presence of black shales has caused repeated problems, significant costs and delays during the implementation of building and construction solutions. Besides the problems linked to weathering, such as heave and sulfate attack on concrete, the main challenge is the safe disposal of large amounts of blasted rock from construction sites.

The Norwegian Geotechnical Institute has developed a new method to correctly place black shales in their lithological succession and characterize their potential for developing ARD, and thus estimate their environmental hazard (Pabst et al., in review). The method is based on geochemical analysis of rock samples and the subsequent comparison of their geochemical fingerprints with known reference samples using a triangular plot method (see below). ARD is estimated by a static approach, much used in the mining industry, plotting acid producing potential (AP) against neutralization potential (NP) (Lawrence and Wang, 1997).

A large building pit was being excavated in the bedrock of an area known for containing black shales. Large amounts of bedrock had to be characterized in order to ensure safe disposal. The disposal alternatives also had economic consequences. Acid producing shales had to be transported to a disposal site for hazardous materials and shales with high U concentrations could be regarded as radioactive waste. Thus a quick and effective method to characterize the black shales was needed to ensure safe disposal, reduce costs and thus not hindering the progress of other activities in the building pit.

Materials and Methods

Before project start, a portable XRF (pXRF), Niton XL3t GOLDD+ Series from Thermo Scientific was calibrated for use for black shales. This was done by splitting crushed rock samples of different types of black shales with a sample splitter and then sending one part for whole rock analysis while analyzing the other part with the pXRF. The whole rock analysis was carried out by an accredited laboratory (ALS Laboratory Group Norway). The black shale samples selected for the calibration spanned a wide range of concentrations for the elements needed to determine: ARD potential - sulfur (S), calcium (Ca); radioactivity - U; and placement in the Cambro-silurian succession – several main and trace elements. Due to various interferences, calibration curves for some elements were inferior and these were not included in the characterization program.

The bedrock was sampled by collecting about 500 g of drill cuttings per sample from various drilling activities in the building pit. An on-site laboratory was set up and the cuttings were split to 10 g samples. The samples were crushed using a mortar and pestle to a grain size $<250\ \mu\text{m}$, and mounted in pellets. The pellets were analyzed using the pXRF mounted in a stand that houses a chamber for the sample. The stand allows longer measurement intervals with a more accurate analysis as the area analyzed and the distance from the sample to the detector is fixed over the measurement interval.

The method described by Pabst et al. (in review) was then used to identify the type of black shale and the potential for generating ARD. Identification was done by comparing the geochemical fingerprint of a sample with the fingerprints of reference samples in triangular plots. Triangular plots are made by plotting the relative concentrations of three elements, and samples from the same horizons will gather in clusters if specific combinations of elements are used. To determine the ARD potential, the acidification potential was estimated by total S content while the neutralization potential is estimated by total inorganic carbon (TIC). The pXRF can measure total S, but not TIC. The assumption was made that the TIC content in shales mainly is due to calcium carbonate, and that most Ca in shales are associated with the calcium carbonate. TIC was then estimated from the Ca concentration.

Norwegian environmental authorities define radioactive waste as materials with an activity of $>1000\ \text{Bq/kg}$. To avoid complicated calculations involving several radioactive elements, such as U, thorium (Th) and potassium (K), a calibration curve was made for U measured by pXRF vs. the total activity of all radioactive isotopes in 15 samples of black shales (Figure 1). Based on this calibration curve an activity of $1000\ \text{Bq/kg}$ gives a U concentration of $97\ \text{mg/kg}$, but to compensate for the error in the calibration curve and the error in the U measurement, the limit of $1000\ \text{Bq/kg}$ was set to equal $85\ \text{mg/kg}$ U as measured by pXRF.

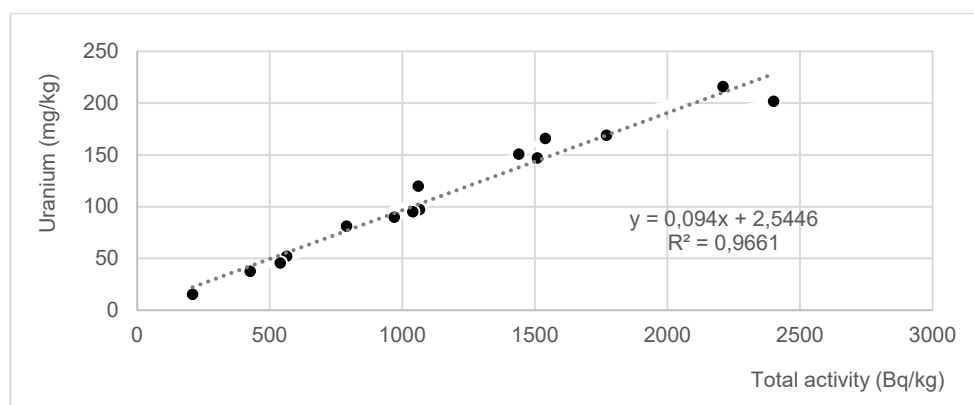


Figure 1 Calibration curve for total activity (Bq/kg) vs. uranium (mg/kg) as measured by pXRF.

Three categories for disposal were then used: 1) Radioactive rock masses with a high potential for generating ARD, 2) Rock masses with a high potential for generating ARD, and 3) Rock masses with an intermediate potential for generating ARD.

Results

More than 100 individual blasts were sampled, analyzed and characterized. Figure 2 shows triangular plots for samples from blasts 133, 137 and 142. The samples from these blasts cluster together with reference samples from horizons 2 and 3a, thus showing that the rock masses sampled belong to this part of the Cambro-silurian succession. In fact, all analyzed samples showed that the bedrock in the entire building pit belonged to horizons 2 and 3a.

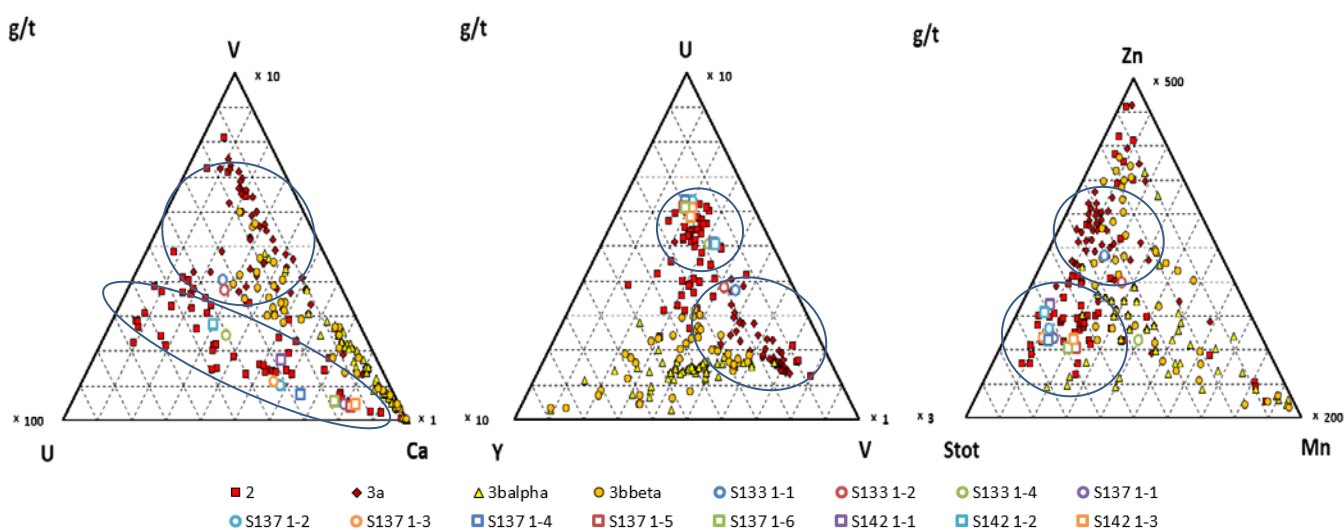


Figure 2 Triangular plots for selected elements and reference samples from horizons 2, 3a, 3b-alpha and 3b-beta in the Cambro-silurian succession, shown for samples from blasts S133, S137 and S142.

The S content in the samples from horizons 2 and 3a typically ranged between 20 000 and 60 000 mg/kg. Figure 3 shows the placement of the samples from blasts 133, 137 and 142 in a plot of AP vs. NP. All samples, except two, fall in the ARD zone. The majority of all samples from the building pit were in the ARD zone, and thus were placed in either category 1 or 2.

Several geochemical differences between horizons 2 and 3a were documented via the analysis. Horizon 3a was found to be enriched in vanadium (V) and sink (Zn), with concentrations generally above 1000 mg/kg and 300 mg/kg respectively. Horizon 2 was found to have higher concentrations of barium (Ba) Ca and S than horizon 3a, generally above 10 000 mg/kg, 10 000 mg/kg and 30 000 mg/kg for these three elements respectively.

U and S concentrations were proportional; the highest concentrations of U was found in layers enriched in S. U concentrations typically ranged between 40 and 200 mg/kg. It was found that horizon 2 had the highest concentrations of U, and these were mostly above the limit for radioactive waste (85 mg/kg as measured by pXRF). The uppermost part of horizon 3a generally had a U concentration below the limit for radioactive waste, but some U-rich layers were identified in the lower part of horizon 3a, with concentrations up to 180 mg/kg.

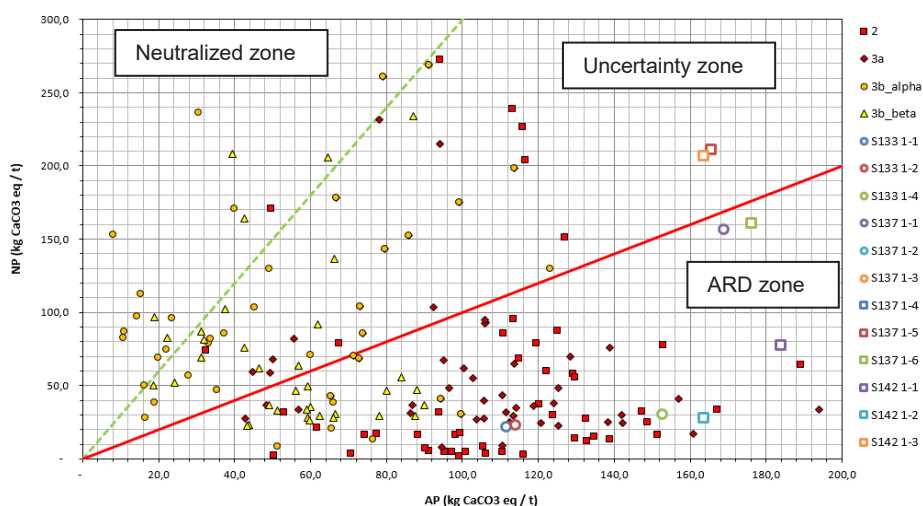


Figure 3 AP vs. NP for reference samples from horizons 2, 3a, 3b-alpha and 3b-beta in the Cambro-silurian succession shown with samples from blasts 133, 137 and 142.

Discussion

Through characterization of the samples it was soon discovered that the rock masses in the entire building pit belonged to either horizon 2 or 3a. Horizon 3a lies directly on top of horizon 2 in the Cambro-silurian succession (Owen et al., 1990), but due to a slanted orientation, most of horizon 3a was situated on one side of the building pit. Once the divide between horizons 2 and 3a was identified, less samples were needed in order to characterize the masses. This is because both horizons 2 and 3a have a high potential for generating ARD, thus, only disposal categories 1 and 2 could be used, and these were in turn distinguished by U-concentration.

By making the necessary assumptions and estimating TIC by Ca-content, there is a risk of overestimating the neutralizing potential in black shales. To avoid mishandling it is thus advisable to include a safety factor for the TIC-estimation. Neutralizing potential can also be overestimated if calcareous nodules are sampled. If black shales are identified as belonging to horizons 2 and 3a however, estimation of ARD potential is not as crucial, as it has been established that horizons 2 and 3a generally have a high potential for producing ARD.

The adapted method allowed for safe disposal of two separate categories of rock mass based on their harmful potential and thus greatly reduced costs as well as not slowing down project progress. The large number of samples taken in this project has provided a vast database of geochemical data about horizons 2 and 3a and their transition zones, which may provide further insight for future projects.

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IMPACT OF CHLORINATED COMPOUNDS IN GROUNDWATER ON STREAMS

– A STUDY ON 30+ CONTAMINATED SITES IN DENMARK

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Background

Chlorinated compounds from contaminated sites may enter surface water bodies as contaminated groundwater discharges into the stream. In this study, we investigated the impact of more than 30 contaminated sites on 28 rivers and streams situated within 250 meters from the sites. The sites were selected by using a GIS-based screening tool developed by the Danish Environmental Agency. The objective of the investigations was to see, if chlorinated compounds or degradation products are detected in stream water at concentrations exceeding the environmental quality standards (EQS). Sites ranged from small dry cleaning facilities to larger steel factories. Groundwater contamination with chlorinated compounds is present at all sites. Even though the plume mapping at some of the sites was incomplete, groundwater flow direction and local hydrogeology suggested that groundwater from the sites was likely to discharge to the nearby streams in all cases.

Aim

In the project's first phase 28 streams were sampled for PCE, TCE and 1,1,1-TCA as well as degradation products (cis- and trans-DCE, VC) downstream of the contaminated sites. The investigations were performed during summer, when base-flow in Denmark is considered to be at its highest and dilution from surface water run-off at its lowest. In total 269 surface water samples were taken and the stream discharge was measured in all streams at the point where plumes were expected to discharge. In the second phase of the project, five sites went through additional investigations to improve understanding of transport pathways and degradation at the groundwater/surface water-interface and mixing in surface waters.

Conclusions

TCE, PCE or degradation products were detected in 11 streams. Most finds were below the environmental quality criteria (EQS). In 5 cases PCE or VC values exceeded EQS. Vinyl chloride seems the compound of most concern as EQS was exceeded at the largest distance from the source zone and in 4 out of the 5 cases. VC was only detected in stream water if the compound was already present in the plume and hyporheic dechlorination was not observed in most cases. Volatilization is an important removal process in smaller streams. In several cases, drainpipes will shortcut the transport from the source zone to the stream, and these cases showed some of the highest finds of chlorinated compounds in the surface water. This is an important lesson for future risk assessment of contaminated sites near surface waters.

Notes

Handwriting practice lines consisting of 20 horizontal dotted lines.

SESSION L

Remediation technologies PART II

Full scale ek-bio treatment of PCE DNAPL in clay till - results and perspectives after 3 years of operation - *Ida Damgaard, Capital Region, Denmark*

In-situ bioremediation of chlorophenol contaminated aquifer - *Jukka Ikäheimo, Pöyry, Finland*

Phytoremediation as a sustainable method for clean-up of hydrocarbon polluted soil in the boreal climate - *Kim Yrjälä, Adj.Prof, Department of Biosciences, University of Helsinki, Finland*

Case study: Cleaning-up the Mountainside; in situ remediation of a large petroleum hydrocarbon plume at a former military base in Sweden - *Jonny Bergman, RGS90, Sweden and Gareth Leonard, REGENESIS, United Kingdom*

FULL SCALE EK-BIO TREATMENT OF PCE DNAPL IN CLAY TILL – RESULTS AND PERSPECTIVES AFTER 3 YEARS OF OPERATION

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Background

In Denmark there is a big need for in-situ remediation methods for low permeable sediments contaminated with chlorinated solvents. An effective and commonly used method is thermal treatment. However thermal treatment has a high energy consumption and is therefore not considered as an environmentally sustainable method. Successful in-situ remediation of low permeable sediments using more sustainable biological degradation methods highly depends on effective and uniform delivery of reagents in the treatment area. Traditional amendment delivery methods based on hydraulic advection mechanisms face limitations in low permeable and/or highly heterogeneous geological settings. To overcome these limitations electrokinetic-enhanced amendment delivery has been developed. One version of this is electrokinetic enhanced bioremediation (EK-BIO) where ionic lactate or similar is delivered through an induced electric field relatively independent of hydraulic properties. An EK-BIO pilot test demonstrated the transport and distribution of amendments (lactate and microbial culture KB-1™) through clay soils in the target area. Rigorous documentation showed that PCE dechlorination in clay soil was achieved. Based on the successful pilot test, a full-scale remediation was implemented.

Aim

In 2012 the World's First full scale EK-BIO was initiated targeting a PCE DNAPL source area in Skuldelev, Denmark. The geology of the site consists of clay till interbedded with sand deposits. The treatment zone, addressed by a network of 15 electrode wells, covers an area of 100 m² to a maximum depth of 10 m bgl. The overall area is divided into two sub-areas, which are treated in alternating stages, each for a period of three months. The polarity of the electrodes is changed to alter the current directions and electric field orientations in alternating stages in order to optimize the EK transport efficiency and to achieve treatment of the entire target zone for remediation. Performance monitoring comprises monthly water sampling for TOC and field measurements, as well as quarterly water sampling for complete characterization of contaminant composition and degradation processes. In addition, soil sampling is also performed at the end of select stages of operation to assess treatment in clay materials.

Conclusions

At present, the EK-BIO full-scale treatment has been operated successfully for three years with encouraging and expected results. Both electron donor and *Dhc* have been distributed throughout the treatment area and complete reductive dechlorination of PCE to ethene is taking place in groundwater as well as in the clay till matrix. Furthermore results so far show increasing degree of dechlorination as well as depletion of the PCE DNAPL mass. In January 2016 confirmatory groundwater monitoring and clay till cores will document the remaining contaminant mass. The operation and design for the remaining clean-up period will be adjusted according to these results. The remediation criteria that can be reached using the method will be evaluated. Further, a comparison of the energy use of EK-BIO towards other methods on the market will be made.

FULL SCALE IN-SITU BIOREMEDIATION OF CHLOROPHENOL- CONTAMINATED AQUIFER

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Abstract

The aim of this work was to develop a microbiological process for cleaning of a chlorophenol-contaminated aquifer in Kärkölä, Finland. The aquifer and local water intake were contaminated in 1976 in a fire where several tons of chlorophenol- (CP) containing fungicide was spread in soil and further to groundwater. Biodegradation was first tested in the laboratory by mixed bacterial culture originated from the contaminated aquifer. These tests indicated that oxygen was prerequisite for degradation of the chlorophenols. In pilot phase solid calcium peroxide was tested as an in-situ oxidant. The pilot results were positive but oxidation capacity in the aquifer was limited within one meter around the oxidation point. Therefore observation well oxidation under the prevailing soil conditions was not suitable method in full scale groundwater remediation (high oxygen consumption, slow oxygen release and slow groundwater flow).

In full scale remediation the aquifer was aerated by oxygen saturated local CP-contaminated groundwater which was infiltrated in the contaminated ground water zone. The aeration was made by a simple ejector. Cold aerated groundwater contains 10...12 mg oxygen/liter. Anaerobic water was pumped from the recharge well downstream into the upstream infiltration well. During the remediation, the aerobic zone has expanded downstream the infiltration well, and after four years of operation the contaminated aquifer has decreased by at least 90 %. The original concentration of chlorophenols in the recharge well water was approximately 3 500 µg/l and is now approximately 200 µg/l. The lowest concentrations in the affected area are now less than 10 µg/l.

This method could easily be applied in in-situ bioremediation of aquifers contaminated also by several other organic aerobically biodegradable chemicals.

Materials and methods

Laboratory experiments. The source of microbes at laboratory testing was water with suspended solids pumped from the contaminated aquifer. These samples indicated high chlorophenol-degrading activity at low temperature (+5 °C) under aerobic conditions but no degradation was observed by those samples where microbial activity was inhibited. The occurrence of chlorophenol- degrading capacity of the microbes was investigated in more

detail in the University of Helsinki / Lahti Ecological Unit. Figure 1a shows test arrangement and Figure 1b summary of laboratory results.

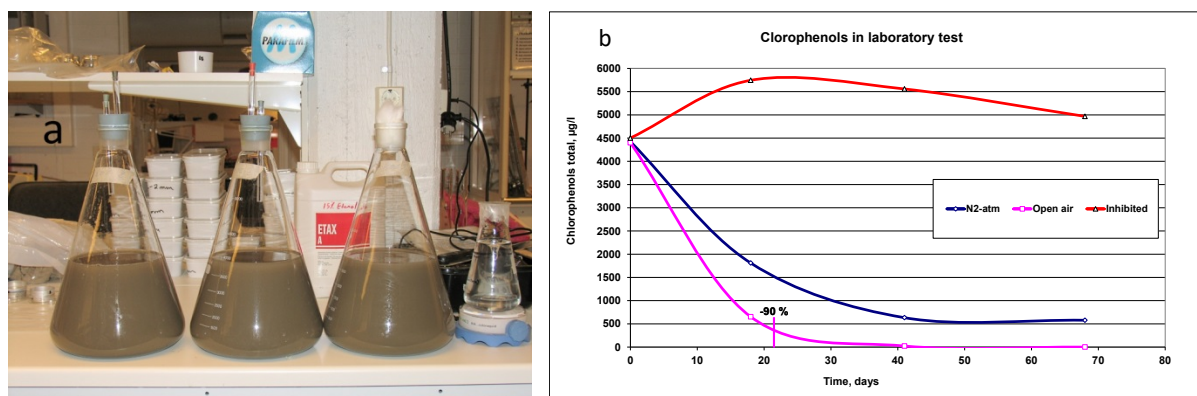


Figure 1. a, Laboratory test arrangement. b, Laboratory test results

Pilot tests. In pilot scale we tested two different aerobic methods for chlorophenol degradation, 1) oxidation in-situ by solid calcium peroxide, and 2) on site UV- light catalyzed degradation.

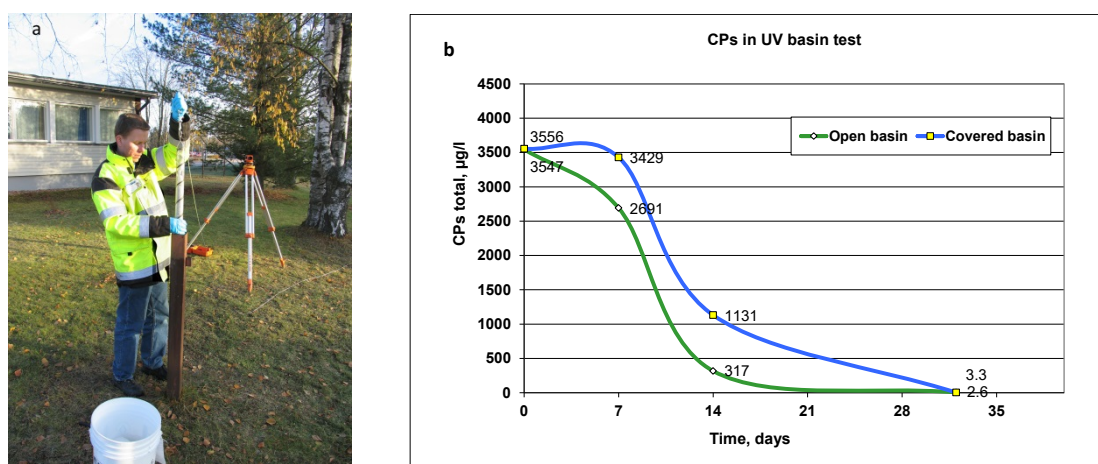


Figure 2. a, Installation of Calcium peroxide tubes in an observation well. b, UV-irradiation test results.

Chemical analytics. Di-, tri-, tetra and pentachlorophenol's and soluble oxygen were analyzed by SGS inspection Services, Kotka Finland.

Conclusions of the Laboratory and pilot testing of the aquifer were:

- Chlorophenol degrading bacteria are present in contaminated aquifer, are active at ground water temperature and degrade all chlorophenol components
- Degradation proceeds only in aerobic environment
- No nutrients (N,P) are needed to add to the ground water for degradation
- Solid peroxide proved to be a potential oxidant but the effect was only local
- Chlorophenols are degraded somewhat photochemically by UV irradiation but it cannot be applied as in-situ
- Complete degradation of 1 gram of chlorophenol requires appr. 0,8 gram of oxygen
- Based on calculations oxygen saturated infiltration water can introduce enough oxygen into aquifer to maintain aerobic degradation

Remediation of ground water

The distance from the point of contamination to the water intake wells and ground water discharge area is approximately 900 meters. Ground water flows along a rock depression close to the bedrock at appr.10 meters depth in a moderate permeable fine sand layer overlaid by silt and clay formations. Ground water is oxygen-less and it discharges to surface waters close to the water intake wells. Thereafter it flows mixed by surface water 3 kilometers in a creek to the nearby lake. Concentrations of chlorophenols in the lake water and sediment have been elevated in recent decades.

Aquifer was aerated by using a closed circle (Fig. 3) where oxygen-less ground water was pumped from a discharge well and aerated while it was infiltrated back into the aquifer 200 meters upstream. Around the infiltration well aerobic zone in the aquifer has gradually expanded, followed by increased microbial activity and decrease of concentrations of chlorophenols. Aeration is carried out by a simple mechanical ejector that increases the concentration of oxygen in infiltration water to the level of saturation. Daily infiltration rate has been about 65 m³ / day.

Precipitation of iron in and around the infiltration well decreases its infiltration capacity. The iron content of the infiltrated ground water is 7 mg/l. After regular removal of the Iron sludge and by occasional acid wash of the well screen the infiltration capacity has remained stable for four years.

Fig 3 shows the closed circle aerated soil bioreactor. The gradient between the recharge and the infiltration wells is increased followed by increased flow rate and aeration of ground water in soil bioreactor. Operation of the process is followed by analysis of chlorophenols and monitoring of ground water levels in the infiltration well and several other observation wells.

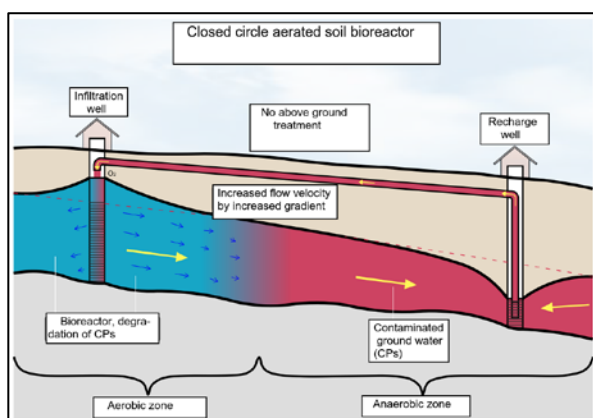


Figure 3. Principle of the remediation method.

Fig. 4 shows degradation of chlorophenols in the main stream of contaminated ground water. The concentration of chlorophenols in the aerated ground water between the recharge and infiltration wells has decreased in 43 months from 2000 – 8000 µg/l to an average level of 70 µg/l. Clear decrease in chlorophenol concentrations is observed in several monitoring wells also downstream the recharge well.

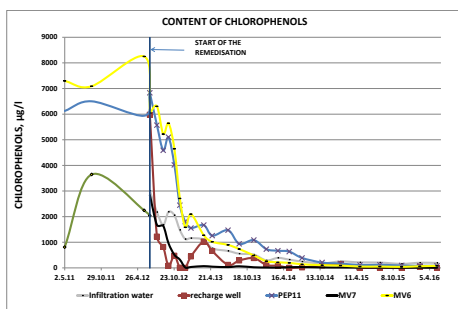


Figure 4. Degradation of chlorophenols during the remediation.

Fig. 5 shows the location of the wells and monitoring points and the heavily contaminated ground water plume. Heavily contaminated part of the aquifer was estimated to contain 75 % of total chlorophenols.

Parts of the chlorophenols are outside (in water and attached in solid material) the aquifer main stream, in less permeable layers where aeration is not effective. Removals of these are intensified by adding peroxide tubes in ground water observation wells.

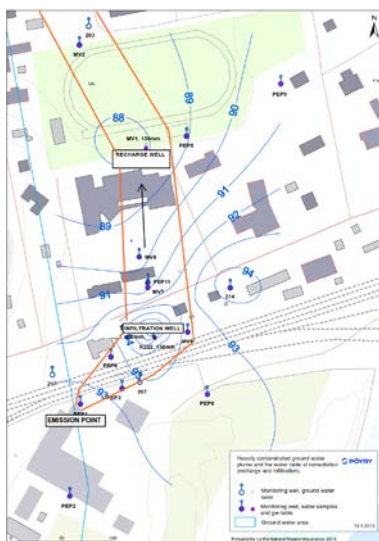


Figure 5.

Discussion

The results of the laboratory and pilot testing indicated that the aquifer contained relatively high quantities of chlorophenol- degrading bacteria. Based on this a full scale In situ remediation of the aquifer was started in June 2012. Lack of oxygen proved to limit the activity of the microbes. The gradient developed by pumping between discharge and infiltration wells increases ground water flow and intensifies aeration. By the end of 2015 (in 40 months) the concentrations of chlorophenols in ground water in this area have decreased from 2000 – 8000 µg/l to an average level of 70 µg/l. A clear decrease of chlorophenol concentrations is also observed downstream the recharge well, 200 to 900 meters from the contaminated point. This method has proved to be a cost effective and simple method to clean chlorophenols of the contaminated aquifer and could be applied in aerobic in-situ remediation of several organic biodegradable compounds.

RHIZOREMEDIATION AS A SUSTAINABLE METHOD FOR CLEAN-UP OF HYDROCARBON POLLUTED SOIL IN THE BOREAL CLIMATE

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In Finland more than 25000 sites are polluted or suspected to be polluted. The present pace of clean-up is too slow. New methods and procedures are needed for speeding up the start of clean-ups. The most common method has been excavation and storage on landfills. This practice omits serious consideration of other options like *in situ* remediation and better risk assessment of the contaminated area. Rhizoremediation of petroleum polluted soil was implemented since 2009 in Haapastensyrjä, Läyliäinen, North-West of Helsinki. Rhizoremediation of aged creosote soil using hybrid aspen was started in 2013 in Somerharju, Luumäki, in South-Eastern Finland. An important part of phytoremediation is monitoring of the bioremediation process. Biological activity was estimated and the microbial communities and individual bacteria identified. To take a step towards sustainable remediation the EU-Central Baltic project, Innovative sustainable remediation (INSURE) was started in September 2015. The heart of the project is working with hydrocarbon polluted contaminated pilot sites in Scandinavia and the Baltics. The central idea is setting up suitable sustainable *in situ* remediation to demonstrate the usability of *in situ* methods. Hybrid aspen and associated microbes is used for clean-up of oil and pesticide pollution in Finland and Latvia.

Introduction

In Scandinavia there is a large number of polluted sites. In Finland alone the number is so big it would take generations to deal with them with the present pace of remediation (1). It can be concluded that the management of polluted sites at present is not sustainable since too many sites are not dealt with causing environmental risks. After the recognition of polluted sites in the 1970's the environmental legislation and remediation practices started developing. Pollutants were classified on the bases of their properties and threshold values were determined. Partly due to very strict implementation of threshold values, excavation and landfill deposits became common practice, which is not sustainable. Better site investigations and information of putative spreading and bioavailability of the pollutants is needed. Microorganisms, bacteria and fungi, have the catabolic ability to break down organic compounds and can well be taken use of.

An important sustainable alternative to excavation is *in situ* treatment where the biology of the soil becomes crucial. In natural attenuation indigenous microbes in soil are able to degrade pollutants when the environmental conditions are favorable using catabolic pathways (2). Rhizoremediation is a



sustainable method for improved biodegradation. The plant is acting like an inoculum by increasing the activity and number of microbes in rhizosphere associated soil and plant associated microbiota. *Populus* tree species have successfully been used in phytoremediation (3).

Root exudates stimulate microbial growth in rhizosphere also by acting as co-substrates for degrading bacteria. The growing plant roots improve degradation conditions by bringing more oxygen to soil increasing the porosity. Different types of bacteria have developed different abilities to break down chemical compounds. The diversity of microbes in soil is huge and that is taken advantage of in phytoremediation of organics (3). Before the advent of modern microbial ecology these microbes were studied by

isolation on nutrient agar plates. It was then realized that only a few percent of the soil microbes readily grow on plates, and that is why genetic methods are obligatory to take use of the huge diversity of microbes in soil (4). The microbiology of phytoremediation has been studied, but much less is available from field experiments and especially temporal studies of the phytoremediation process (3).

Materials and Methods

Hybrid aspen (*Populus tremula x tremuloides*) and European aspen clones were planted in oil polluted soil from an oil spill by a motorway in Southern Finland in a long term field study. The polluted soil (0,8 % oil) was transported to the former METLA now LUKE research unit in Haapastensyrjä 2009.



Different aspen clones were tested for their ability to cope with oil pollution. The rhizoremediation process was monitored by measurements of plant growth and soil microbiota. Both functional and structural (phylogenetic) diversity was ultimately determined by 454-pyrosequencing

and bioinformatic analysis. Rhizoremediation of an aged creosote polluted site using hybrid aspen was started 2014 in Somerharju, Luumäki. The risk assessment included study of the extent of pollution tracking the heavy pollution to a 1.3 ha area. Geostatistics, ArcGis, was used to determine the spread of pollution after chemical analysis. The microbial activity in polluted soil was estimated by MPN for hydrocarbon degraders, basal respiration assay and FDA hydrolysis assay to estimate general enzymatic activity in polluted soil.

Results

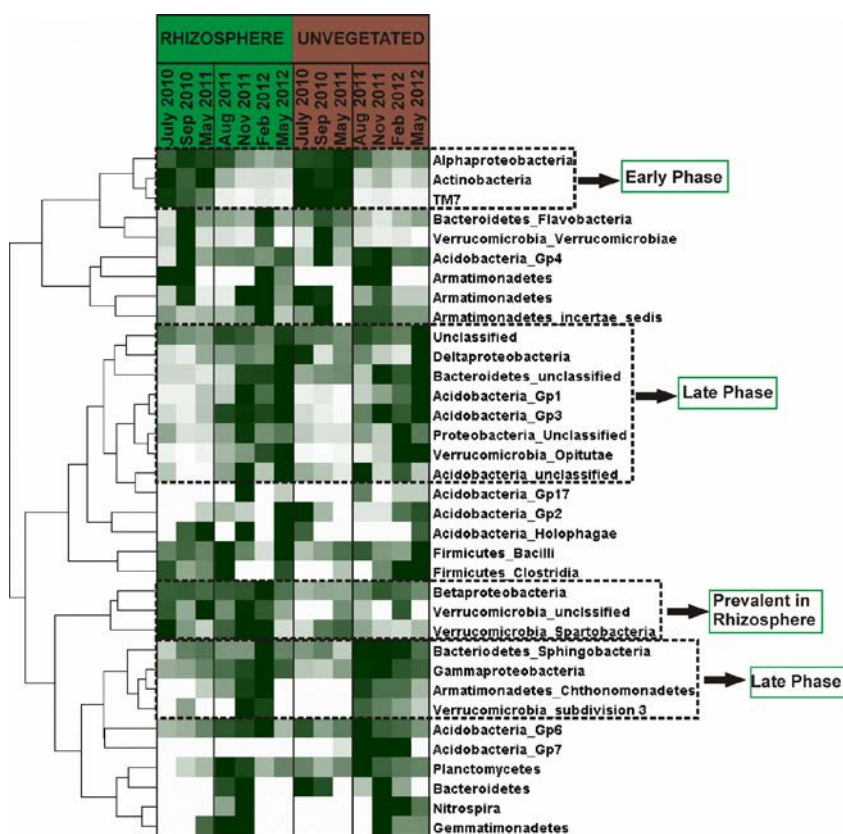


Fig 1. Bacterial taxa in rhizoremediation of petroleum as a function of time.

Bacterial succession and spread of bacteria in rhizoremediation of petroleum and creosotes

Alphaproteobacteria and Actinobacteria were most abundant in the early phase of rhizoremediation of petroleum. Gammaproteobacteria, Bacteroidetes and Acidobacteria were abundant in the later phase of the rhizoremediation process. Both basal respiration and FDA hydrolysis activity was generally highest in the spots where hydrocarbon pollutant concentration was highest.

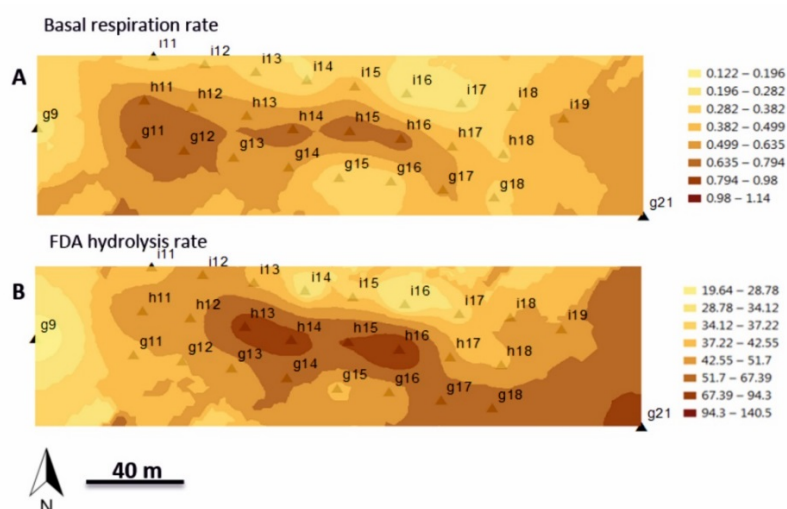


Fig.2. Krigged maps of microbial activity of the aged creosote polluted site in Somerharju, Luumäki.

Discussion

In rhizoremediation of petroleum polluted soil (0.8%), oil was fairly toxic to the aspen plants and root development was initially slow. A clear succession of bacteria could be shown from early bacterial populations to late phase populations. In aged creosote polluted sandy soil PAHs were important substrates for distinct bacterial taxa. The biodegradation is still continuing after the initial dispatch of creosotes in the 1920's to 1940's. The most abundant bacterial populations were different in aged pollution compared to the fresh petroleum pollution.

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Case study: Cleaning-up the Mountainside; *in situ* remediation of a large petroleum hydrocarbon plume at a former military base in Sweden

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Abstract

In 1958, an explosion at a secret military storage facility in a remote part of Sweden resulted in more than 14,000 m³ of fuel sweeping down the mountainside and contaminating the soil and groundwater of the surrounding forest. This, now derelict, site is scheduled for redevelopment for other purposes. RGS 90, a Swedish remediation specialist, has been commissioned with cleaning up the site. Regenesisis and RGS 90 have worked together to create an *in situ* remedial strategy to address free product and dissolved phase contamination in fractured bedrock, a boulder field and unconsolidated soils beneath the remains of the base and the forest beyond. An integrated *in situ* treatment approach proactively combining physical, chemical and biological technologies both spatially and in sequence was selected, with the combined application presenting clear time and cost benefits over the projected use of any one of the technologies used alone.

Introduction

During the cold war, Sweden held secret fuel supplies in underground in readiness should war break out. These would then refuel jets using specially designed sections of road as makeshift runways.

One evening, in the summer of 1958, at one such fuel depot above a village called Moheda in the municipality of Alvesta, southern Sweden, the ventilation system in the storage bunker lost power and switched off. In the rooms and spaces around the huge fuel tanks, dangerous levels of flammable vapours began to build up. When the site personnel returned to work in the morning, they restored the power, instantly causing an explosion to tear through the stores. Sadly, this resulted in loss of life. Also, the explosion ruptured some of the tanks, spilling fourteen million litres of fuel (45% jet fuel, 42% petrol, 13% diesel). The fuel flowed out of the bunker and downhill into the forest, rushing over the mossy boulder field between the pines and soaking into the soils beneath. 300m from the bunker entrance, the fuel pooled in a hollow just next to the outer-most houses of Moheda, creating a lake of petrol. Fearing further fires in the area, the emergency response was to dose the area in water and cover it in soil.

Elsewhere, fire was used as the solution. The fuel had, through the sewages system, flooded onto a lake, covering the surface. In order to remove the contamination as quickly as possible, the surface of the lake was set alight, where it continued to burn for several days. In total, around 45,000m² of mountainside was impacted, with free phase fuel and dissolved contamination being created in the fractured bedrock, glacial till, moraine and made ground across the site. After the immediate spill response, the impacted areas were left alone and the base was repaired and continued to operate until 2004, when it was decommissioned, and following soil and groundwater investigations showed the need for remedial action.

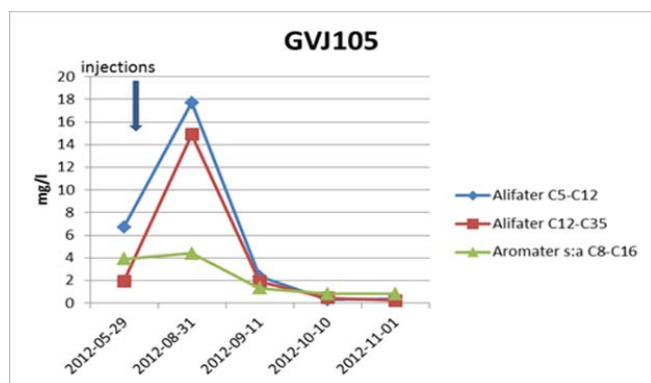
The initial proposal provided by the client to RGS 90 consisted of bioparging and *in situ* chemical oxidation (ISCO) using more than one million litres of hydrogen peroxide. RGS 90 had concerns regarding the inherent environmental and H&S risks, as well as its validity due to the low permeability and heterogeneity of the site. RGS 90 approached REGENESIS, an international remediation solutions provider, to assist in the development of an alternative strategy including the completion of pilot studies to prove the efficacy of the treatments and increase the accuracy and cost-effectiveness of the final doses used.

Materials and Methods

Pilot studies

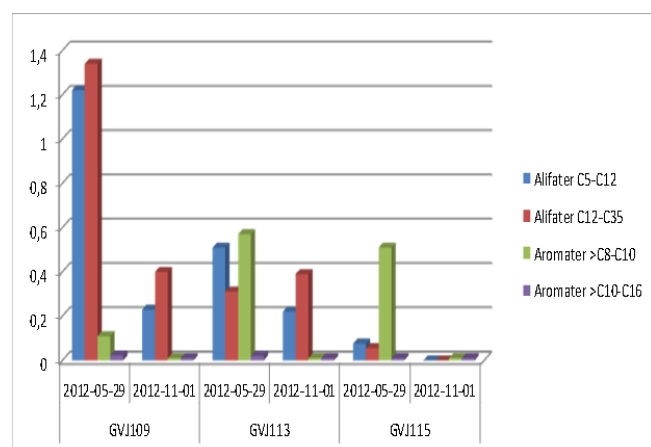
Two separate pilot studies were completed on the site in 2011; one in an area of higher contaminant concentrations where some Light Non-Aqueous Phase Liquid (LNAPL) was suspected to exist within the soil and fractures in the bedrock. An area of 10*10 m² was elected and nine injection wells were installed within the area. Sampling of groundwater was carried out in 8 wells, within and close to the injection area. Groundwater samples were taken before, during and after the injections. The area was treated with three application rounds of RegenOx[®]. RegenOx is designed to chemically oxidise high concentrations of organic contaminants safely and without excess heat and pressure being produced.

The second pilot study was completed using ORC Advanced[®] in order to trial the treatment of parts of the site impacted with dissolved phase petroleum hydrocarbon contamination only. An area of 10*10m² was elected and direct push injection was carried out in 16 points within the area. Sampling of groundwater was carried out in 8 wells within and close to the injection area before and after the injections. Groundwater samples were taken before and after the injection. The application of ORC Advanced created and sustained strongly aerobic conditions for up to 12 months from a single injection in order to provide Enhanced Natural Attenuation (ENA) of the petroleum hydrocarbons within the groundwater.



In the RegenOx pilot trial area, a 50-95% reduction in contaminant concentrations was seen due to in situ chemical oxidation (ISCO). In areas where adsorbed contamination or LNAPL was encountered, the analysis showed dissolution of the contaminants into the groundwater where they were then rapidly degraded

Figure 1: Results (point GVJ105) from RegenOx Pilot Area showing COC reaction to injection over time to non-detect.



In the second pilot study area, a single application of ORC Advanced was made across an area approximately 10m by 10m. As can be seen in Fig.2, 95-99% reductions in the dissolved phase contamination were achieved within a few months, with the technology still actively promoting the biological degradation of any residual contamination, beyond this time.

Figure 2: Results from ORC Advanced Area showing concentrations in 3 of the monitoring wells before and after treatment.

The results from the pilot trials allowed RGS 90 to successfully prove that the remedial approach was valid and could be extrapolated to address the extensive TPH contamination across the site. The results assured the Swedish Armed Forces that this would be the most economical, technically viable, and effective integrated remedial solution at the site.

Full scale works

Area C and D

The decision was made to remediate the site in stages, with the smaller, upgradient areas being treated first (C and D-area). An extensive array of thirty boreholes were installed on a 20m by 20m grid, in order to further delineate the extent of the plume and improve the resolution of the contaminant concentrations and LNAPL distribution within it. The boreholes were then used as validation wells for the main works.

The data gathered from this work and the findings of the pilot study allowed REGENESIS and RGS 90 to refine the treatment design. It was determined that areas showing >10mg/L total petroleum hydrocarbons (TPH) and/or the presence of LNAPL would be treated with three rounds of ISCO (provided by RegenOx), followed by ENA (using ORC Advanced). Areas with between 4 and 10mg/L would be treated with intense ENA (a high dose of ORC Advanced) and areas with <4mg/L would receive a less intense ENA treatment (a lower dose of ORC Advanced). This approach would allow for the most cost-effective, applicable approach and would avoid wasted/misplaced product.

The first areas to be treated on the site required only dissolved phase contamination treatment using ENA. In December 2013, RGS 90 completed the injection of ORC Advanced into 257 points over an 8 week period. The application used direct push injection, see Fig 3, by which a hollow rod is driven into the ground and the requisite dose is injected into the contaminated part of the aquifer. Due to the geology a series of aliquots across the target thickness was not possible since insufficient sealing resulting in day lighting of product. Thus, since ORC-Advanced is distributed by diffusion required spreading of oxygen was assumed to occur and has been observed.

Results and discussion

Upgradient Areas (Area C and D)

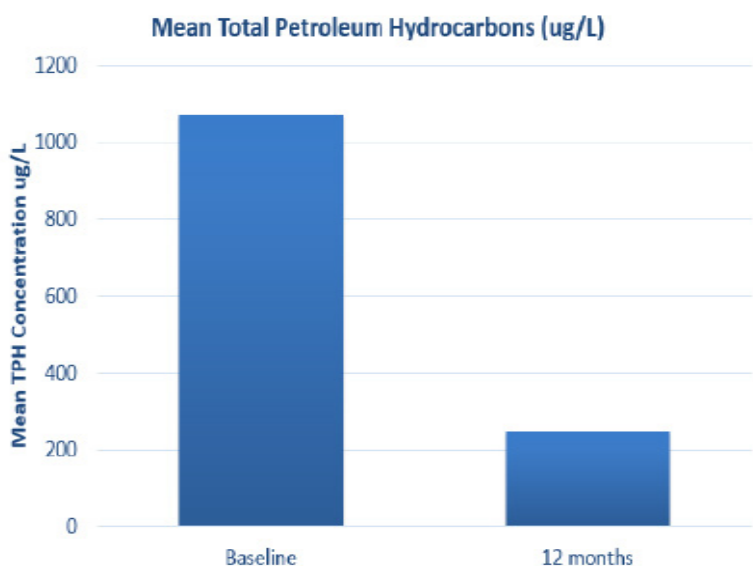
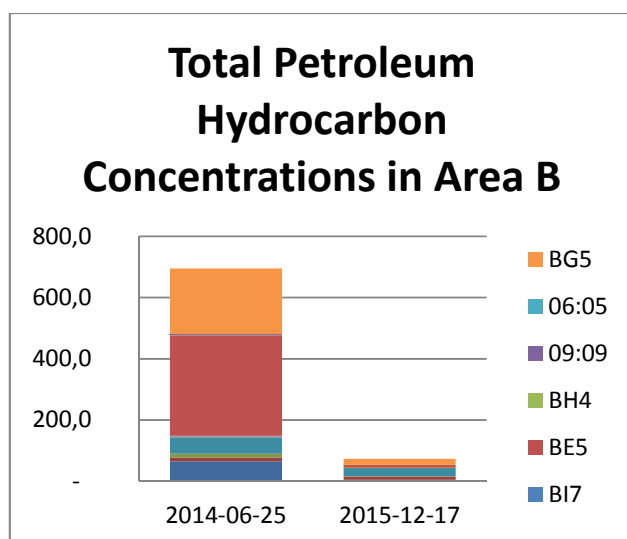


Figure 3. Average concentration reduction in area C and D. 28 of 30 monitoring wells (93%) reached target in one injection.

Validation sampling has been completed in 2015, which shows that TPH concentrations have dropped from a maximum of 12 mg/L to non-detect in most cases. Two monitoring wells showed elevated. One of them (C7) is situated in the outskirts of the treated area and might be suffering from influx of untreated contamination. The other (GVB34) is situated in the centre of the most contaminated area. Continued monitoring will determine if further action will be needed or if continued natural attenuation will be enough.

Downgradient Areas (Area B1-B3)

). An extensive array of 60 boreholes were installed on a 20m by 20m grid, in order to further delineate the extent of the plume and improve the resolution of the contaminant concentrations and LNAPL distribution within it. The boreholes are then used as validation wells for the main works.



During delineation of Area B1-B3 a larger area of free phase product was detected. Also high levels of adsorbed contamination were detected. Due to this RGS 90 has used multiphase extraction in addition to RegenOx PetroCleanze and ORC Advanced since this is most cost effective when removing higher levels of contamination.

Figure 4. Results from selected wells showing significant reduction in concentrations from baseline to first sampling round after MPE and ISCO injections. It is anticipated that one year of monitoring remains, in order to reach target levels in all wells using Enhanced Natural attenuation (ENA) following ORC Advanced injection.

Conclusions

This project is an excellent example of the value of a step-by-step approach to remediation; the initial concept was open to discussion and revision, which resulted in further site investigation and pilot studies to be undertaken. These then informed the full-scale remediation design, resulting in the most accurate and cost effective treatment of the site. The project demonstrates the ability of integrated in situ techniques to meet the challenges of variable concentrations, free product, a heterogeneous formation and difficult terrain. This site shows that in situ remediation is capable of providing solutions to difficult, large scale and complicated problems, which would otherwise have relied on more expensive and disruptive traditional remediation methods. It is perhaps also fitting that a problem that started deep within the ground should also be resolved beneath the soils of this quiet Swedish mountainside.

Posters

Wet Separation techniques, from niche recovery to common application for solid waste recovery

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Background

Recovery of sand from soils and waste by wet separation is an expanding business on the European continent. Next to this more common extraction of sand, separation of different waste like glass, plastics, slags and metals prove to be economical in a circular economy. Not all business models have proved robust under for example increasing energy cost or falling commodity prices, but the geographical spread of the new treatment centers and new fields of application, show that this will be a lasting trend for many years to come.

Aim

The conventional and mainstream application of wet separation is a process most used in the commodities market. As an extraction process of, for example, sand recovery or an additional process in the coal mining industry. Tax exemptions are mainly the reason why wet separation techniques found there entry into the European waste market in the mid-'90. By giving an overview of different soil washing applications in both contaminated land and waste applications, a trend is discovered in different regions in Europe. Various cases are illustrated to prove the trend towards recovery in a circular economy, but the cases also explain where companies and processes failed.

Conclusion

Recovery of sand from soils and waste by wet separation is an expanding business on the European continent. Next to this more common extraction of sand, separation of different wastes like glass, plastics, slags and metals prove to be economical in a circular economy. Not all business models have proved robust under for example increasing energy cost or falling commodity prices, but the geographical spread of the new treatment centers and new fields of application, show that this will be a lasting trend for many years to come.

Environmental challenges and solutions during beneficial use of excess stone masses from large infrastructure projects in Norway

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Background

Large infrastructure projects, ranging from highway constructions to railway and metro upgrades, are being planned and implemented in Norway these days. The projects often include long stretches of tunnels, producing large amounts of excess blasted stone masses. We will look closer into the beneficial use of these masses.

Aim

Depositing excess stone masses from tunnel constructions into the sea is often considered more beneficial than depositing the same masses on land. New land is created and big on-land deposits are avoided. However, depositing millions of cubic of blasted stone masses into the sea also has its challenges. Transportation and deposition of this large quantity of masses need to be planned in detail to be approved by the authorities. "Can the sea bottom support the added load", "are the sediments at the deposit site contaminated", "are there any red list species registered", "who will be the owner of the new land", are some of the questions to take into consideration before a deposit site is approved.

There are many environmental challenges to take into account once the site is approved and the work begins. The masses contain remains from the blasting that can be harmful to biota, like leftover blasting chemicals (nitrogen containing nutrients) and plastic fibers used in the shotcrete. Contaminated and non-contaminated fine-grained materials are mobilized during deposition of the stones, creating high turbidity conditions that might lead to severe light conditions and low biological productivity. Particles are resettling on fish and plants, and contaminants can potentially spread over a big area.

Appropriate solutions for these challenges depend strongly on local conditions. It may include the construction of a buffer layer of for example sand before dumping of the blasted masses take place, securing the area with silt curtains or other barriers to stop the spreading of fine-grained material and strict working procedures related to measured turbidity in the water column.

Conclusion

Environmental design of the works according to the Norwegian environmental legislation will be illustrated with five Norwegian case studies at different stages in the process; planned, ongoing and finished.

CAPACITY OF SOLID INDUSTRIAL BY-PRODUCTS TO NEUTRALIZE ACID MULTIMETAL WASTEWATER

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Abstract

Wastewater produced in the mining industry is typically very acidic and high in dissolved metals and, thus, poses serious environmental risks. Traditionally, wastewater is treated with manufactured chemicals. Production of the chemicals requires, however, energy and raw materials. The utilization of industrial by-products or geomaterials (geological materials) is a low-cost alternative to treat wastewater as these materials are anyway produced in other branches of industry. Wastewater treatment with geomaterials is based on the removal of elements by means of precipitation or surface adsorption, both of which are highly pH-dependent processes.

In this study, acid multimetal wastewater from Talvivaara mine was treated with three by-products (steel slag, apatite mine tailings and Sachtofer PR) of Finnish industry. To study their neutralization capacity, geomaterials were incubated with waste water (solid to solution ratio of 100gL^{-1}) for 1, 7 and 21 days and then titrated to pH 7. The amount of added base and all corresponding pH values during the titration process were recorded. Concentration of selected elements were measured with ICP-OES to calculate the metal removal as a function of pH.

In the untreated wastewater, pH decreased with time as a result of protons produced in hydrolysis of metal cations (e.g. iron & aluminum). Moreover, oxidation of ferrous iron to ferric iron contributed to further acidification of wastewater. Thus, the base consumption increased significantly with prolonged incubation time. As for geomaterial treated samples, part of the solids were dissolved gradually by consuming protons in wastewater and, consequently, neutralized part of the acidity. All the geomaterial treated samples showed substantial decrease in the base consumption; among which steel slag increased pH most efficiently and, accordingly, decreased the base consumption most effectively.

Acceptability of contaminated soils and waste materials in landfill structures

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Background

The acceptability of secondary materials, such as contaminated soil and waste materials, is limiting their use in civil engineering structures. Since the criteria used for primary aggregates are not suitable for all materials, the common testing methods and requirements should be agreed for each application, as the project UUMA2 is pursuing.

Aim

In the paper, problems related to the quality, both chemical and mechanical, of the contaminated soils and waste materials used in landfill structures are discussed based on the recent landfill projects and literature. A testing protocol based on requirements set on natural materials is proposed to promote the use of recycling materials and to unify the practice.

Discussion

Primary aggregates and soil materials can be replaced by waste materials in landfill structures thus saving renewable natural resources. Contaminated soils contain often stones, concrete, bricks and other coarse grained mineral particles which could be used, e.g. after sieving as a drainage layer in a landfill bottom structure. Potentially, fine graded materials could be used as a protective layer on a geomembrane or as a liner improved with bentonite.

Use of waste materials is promoted especially between the bottom liner and capping liner, since the potentially dissolving contaminants can be collected together with leachate from the waste body. However, the material may have effects on waste processes and leachate quality and decrease the service life of geosynthetics and bentonite structures. A typical harmful effect is a precipitation caused by calcium and magnesium resulting clogging. In addition, the waste or leachate can affect the reused material, by increasing the metal diluting or accelerating the deterioration processes. They can also react causing gaseous emissions.

The landfill structures are regulated by an environmental permit. Therefore all materials used have to be approved by the owner, technical supervisor and the environmental supervisor. In project specifications waste materials are seldom mentioned, if not especially required by the owner. Typically the contractor is offering the material and is also responsible for proving the technical and environmental suitability. However, there are no general methods or requirements how the suitability should be demonstrated for each purpose. The soil investigations and tests made for the contamination evaluation of a site are not sufficient to prove the technical properties. During the excavations the material typically varies and it's not possible or economical to separate certain type of material for reuse.

SCREENING STUDY OF PERFLUORINATED COMPOUNDS IN THE FINNISH DEFENCE FORCES

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Background

Perfluorinated compounds or PFCs are a large group of compounds that have been widely used in industrial and consumer products due to their ability to resist water, oil and stains. Therefore, PFCs have been also used in the Finnish Defence Forces (FDF). Health concerns and persistency in the environment led to the need to carry out a study within the Defence Administration. Overall 14 perfluorinated compounds were included into the analysis package. Groundwater ($n = 18$), surface water ($n = 6$), waste water ($n = 5$), soil ($n = 4$) and sediment ($n = 3$) samples were taken. All branches of the FDF (Army, Navy and Air Forces) were represented in the study.

Aim

The aim of the study was to collect information about the occurrence of PFC's in different environmental compartments within the FDF sites. Purpose was to focus on those actions and areas where PFCs were suspected to be released into the environment due to usage of certain products, maintenance work and emissions. Point of interest in this study was also the extent of different PFCs analyzed in individual samples and the variety of concentrations.

Conclusion

Results of the study show a large variety of individual compounds and levels of concentrations. PFCs above the LOD were found from 18 samples total (50 % of all of samples). As expected, the most dominant compounds were perfluoro-octane sulfonate PFOS (36,1 % of all samples) and perfluoro-octanoate PFOA (36,1 %). Interestingly, several other compounds were also frequently detected: heptafluorobutyric acid PFBA (30,6 %), perfluorohexanoic acid PFHxA (30,6 %) and perfluoroheptanoic acid PFHpA (30,6 %). Highest concentrations were found from areas where firefighting foams have been used continuously over long periods of times. The highest concentrations were determined from Liekkilä practice area where sum of all compounds Σ PFC was 17 750 ng/l and 1 834 ng/l, analyzed from ground water. Highest concentrations of surface water samples were analyzed from Liekkilä (Σ PFC 639 ng/l) and from a landfill site of Rissala garrison (Σ PFC 84,9 ng/l). Concentrations from soil samples that were above the LOD were found near former garrison of Kauhava (Σ PFC 291 μ g/kg and 140 μ g/kg). The highest number of perfluorinated compounds in one individual sample was analyzed from the waste water of textile washing and maintenance facility of Säkylä garrison, altogether 11 different compounds (Σ PFC 726 ng/l).

Health standards and environmental guidelines are focusing in PFOS and PFOA compounds and their derivatives. Consistent guidelines that can be used for all PFC compounds are still in process. Screening study gave valuable information about the occurrence of perfluorinated compounds in areas where the FDF operate. Additional environmental studies will be conducted in sites where high concentrations were found. Preliminary risk assessments of the fate and transport, but also of the possible health and environmental impact of PFCs may be carried out in areas of high concern.

PFAS - A THREAT TO OUR GROUNDWATER RESOURCE? SCREENING OF DANISH DEFENSE SITES

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Background

PFAS is an abbreviation for **PerFluoroAlkyl** and **PolyFluorAlkyl** **S**ubstances. These substances have been used in many products due to their unique surface-active properties repelling both water and oils. However these substances have undesirable health and environmental effects and their use or disposal can cause releases which impact our groundwater resources.

Aim

Danish Defense Estates and Infrastructure Organisation (DDEO), has initiated an investigation to identify and investigate activities at Defence sites, where products containing PFAS compounds may have been used and thereby can have caused groundwater contamination. The main focus for these investigations has been to identify the potential groundwater threat.

Conclusion

DDEO has analysed approximately 350 water samples for 10-15 different PFAS substances and 169 of these water samples have been taken close to areas where PFAS containing products have been used. The following activities have been investigated: firefighter drill areas at Danish Defence air bases (both foam nozzles and handheld extinguishers), foam storage areas, waste disposal tips, paint shops, activities involving wax and polish or hydraulic oil, weapon and metal plating workshops as well as Danish Emergency Management Agency's firefighter training areas.

The results have been analysed in relation to the level of groundwater pollution, PFAS composition and the type of activity. The impact on the groundwater resource and the PFAS composition in the groundwater differs according to the source type and activity.

The Danish Environmental Protections Agency (DEPA) has defined a groundwater and drinking water quality criterion of 100 ng/l for the sum of 12 specific PFAS. PFAS substances have been detected in many water samples and the groundwater quality criteria is exceeded for the majority of water samples taken in areas where firefighting foams have been used in training drills. Up to 4,350 times the DEPA groundwater quality criteria was found in one water sample from a Danish Defence firefighter drill area in Denmark, but similar contents have previously been found at military sites both in Sweden and USA. The screening at Defence sites has shown that firefighter drill areas pose the greatest PFAS threat to the groundwater resource, but the threat from workshop activities and depots/waste dumps is assessed to be low. However, it should be noted that only a limited data set was collected for the assessment of the workshop activities and waste dumps/depots.

Activation of Sodium Persulfate to Create Oxidative and Reductive Treatment Pathways

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Mike Mueller (PeroxyChem Environmental Solutions, Zirl, Tirol, Austria)

Background

Activated sodium persulfate has been implemented for over 10 years to successfully remediate sites with a wide variety of contaminants of concern including petroleum hydrocarbons, chlorinated solvents, pesticides and energetic compounds. The ability to treat different contaminants has been attributed to the activation method and subsequent formation of the sulfate, hydroxyl, and superoxide radicals. These different radicals allow for the treatment of contaminants by both the oxidative (hydroxyl and sulfate radicals) and reductive (superoxide) pathways. It has been shown that the radicals formed are different for each activation method, increasing the importance of selecting the proper activation method for each site. Conventional methods of activating persulfate include iron chelates, alkalinity, heat, and hydrogen peroxide. .

Aim

This presentation will focus on a discussion of activation methods, the formation of oxidative and reductive pathways for each method, and recent developments regarding sodium persulfate including the development of an organic activation method. A case study highlighting the reductive pathway of activated sodium persulfate will also be presented.

Conclusion

The presence of reductive pathways that are created with specific activation methods of an oxidative technology is critical in understanding the potential application of an activated sodium persulfate technology. These reductive pathways allow activated sodium persulfate to treat a wide array of contaminants of concern, including highly oxidized compounds such as carbon tetrachloride and 1,1,1-trichloroethane, in addition to oxidizable contaminants such as chlorinated ethenes or petroleum hydrocarbons. Organic activation of sodium persulfate and evidence of oxidative and reductive pathway, as well as other key characteristics of this emerging technology, will be presented.

Long Term Pilot Testing in Oslo Airport along a Runway, to prevent unacceptable impact on Norway's largest groundwater reservoir from de-icing compounds.

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Bente Weiding (AVINOR, Oslo Airport, Norway)

Background.

In 1998, Norway's largest airport was established 50 km outside Oslo. The airport is located on Norway's largest groundwater reservoir, and a condition for the operation of the airport is that the groundwater quality must be unchanged. During the winter, many of the planes have to be de-iced before take-off depending on the weather conditions. The planes are de-iced on a facility with collection of excessive de-icing compounds, but to prevent icing during take-off the wings are soaked with glycol. Measurements along the runway show a spill from the planes during take-off of more than 200 t glycol every year infiltrating the soil and the groundwater 7 meters below the ground. After 6-7 years of operation, many of the monitoring wells showed both increasing, TOC, Fe and Mn concentrations, content of de-icing compounds and even methane. Since a run off collection system along the runway is very costly, the airport has completed both a testing phase and a pilot project with a much more cost effective and sustainable soil venting process to meet the accelerating impact on the groundwater.

Aim.

In late 2011, both air sparging and soil vapor extraction test were performed to check the ventilation conditions and to access the initial remediation effect on both the unsaturated and saturated zone. Special injection and extraction wells were installed with measurements in existing monitoring wells. The tests showed a clear improvement in the groundwater but apparently with some side effects. No significant improvement of the biodegradation of de-icing compounds in the unsaturated zone was measured. Based on these results, a pilot test was performed in the period October 2013 to February 2015 with bio sparging (55 m³/h) in three injection wells placed in the most contaminated area. During the test period, intense monitoring in down streams wells with chemical analysis of TOC, glycol, formiate, O₂, Fe, MN, SO₄, Ni and Acetate was performed. The objective was to monitor both positive and potential negative impact from the air sparging. The results from the test area were compared with a historical study of more than 2500 chemical analysis from monitoring wells all over Oslo Airport.

Conclusion.

The historical study of the existing monitoring results shows clearly how the natural bio degradation capacity of de-icing compounds in the unsaturated zone collapses after 7-8 years due to the extensive load of glycole released in the spring. With the steady increasing number of planes from the airport, the study shows that the negative impact on the ground will accelerate in the future if no remedy is installed. The result from the long term pilot test shows restoration of the natural background level for TOC, Fe, O₂ and Mn. The de-icing compounds in the groundwater are completely bio degraded. Methan concentrations are not significantly reduced. The results show increasing content of Ni and SO₄ in the test area due to pyrite oxidation, but a comparison with unaffected monitoring wells shows that background levels are restored, so this is not a side effect. Based on the results, Oslo Airport has in the summer 2015 installed a bio sparging plant with 75 injection wells covering 1200 m runway with an injection capacity of 550 m³/h. Future monitoring will demonstrate if this installation will manage to keep the groundwater quality unchanged in a cost effective way.

SOIL VAPOUR EXTRACTION OF WET GASOLINE CONTAMINATED SOIL MADE POSSIBLE BY ELECTROOSMOTIC DEWATERING; LAB SIMULATIONS APPLIED AT FIELD SITE.

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Background

A former fuel station in Jalasjärvi, Finland was treated *in situ* sequentially with different methods. After several approaches, including soil vapour extraction, the dense original portion of the soil beneath the gasoline pump location, ca 100 m³, was still contaminated with BTEX, at some hotspots > 15000 mg kg⁻¹.

Aim

Novel approaches to clean the soil were considered after only partial earlier success. After a period of electroosmotic water/nutrient circulation using 0.5 V cm⁻¹ DC, the diesel in the soil had been degraded by biostimulation, but the BTEX concentration was still too high. While considering options, the DC current was kept on for six months during the winter.

Conclusion

The DC current turned out to have dewatered and warmed the soil. The moisture level had dropped from ca 85% of water holding capacity down to 59% and the temperature was 18°C. The soil also smelled of gasoline. In contrast to the situation with the original wet soil, BTEX was in lab conditions found to volatilize very efficiently from the dewatered soil. When the soil vapour extraction treatment was renewed at the fuel station site using perforated plastic tubing installed horizontally at ca 1 m depth in the dewatered soil at the contaminated site, the treatment was efficient and the soil was decontaminated in two months.

BIOLOGICAL *IN SITU* REMEDIATION OF DIESEL CONTAMINATED SOIL AND A LABORATORY SCALE COMPARISON OF BIOSURFACTANTS

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Background

Tankki was a three year project administrated by Lahti University of Applied Sciences that ended in 2015, aiming at minimizing the risks connected to oil tank usage and gaining insight into alternative remediation methods for diesel-contaminated soils.

Aim

In Latojantie 6, Hollola a diesel-contaminated area was treated biologically *in situ* by adding oxygen as grainy calcium oxide and a mixture of nitrate and ammonium nitrogen via water distributed within the polluted landmass. The treatment lasted six months and ended in October 2014 and was performed by Nordic Envicon Oy and Helsinki University Department of Environmental Sciences in 2014.

In a separate laboratory scale study two biosurfactant products, cyclodextrin and rhamnolipid, were compared in their possible benefits to a similar bioremediation procedure. The Study consisted of two four month phases: during the first one the oxygen and nutrient levels weren't optimized to mimic a more pessimistic field conditions. During the second phase the optimization was done with calcium oxide as the oxygen source, methylene urea as the nitrogen source with 10:1 C_{org}:N ratio, and the phosphorus as a phosphate buffer.

Conclusion

The *in situ* treatment had a possible positive effect on the contaminant levels. The laboratory scale results showed that with added cyclodextrin it was possible to reach the oil concentrations at which nitrogen became the theoretically restricting factor faster than in the control experiment. Individual rhamnolipid samples showed increased amounts of bacterial 16S rRNA gene, but not real statistical significance was observed and the reductions in C10-C40 levels remained close to those of the control experiment. The optimization of oxygen and nutrient levels showed a clear response in the amount of the 16S rRNA gene but no significant difference in C10-C40 levels. The carbon contained in the methylene urea may have been acting as an alternative and a more readily available carbon source for microbial digestion. Taken into the field scale, the cyclodextrin could shorten the time needed for the removal of the contaminant to a desired level, but with the cost of the product taken into account, the time would have to be shortened substantially for a real financial benefit.

**Innovation in Groundwater Remediation:
Case Study Examples of the Treatment of Dissolved Phase Contamination
Using a New, Fast-Acting, Injectable Liquid Activated Carbon (LAC) Technology**

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Background

In situ bioremediation is an established and effective remediation approach that is widely used around the world. The approach benefits from low cost, with minimal site disturbance. However, in situ bioremediation remains challenged by long remediation time frames and uncertainty in reaching very low target concentrations. This talk explains and demonstrates an innovative remedial technology, which has been developed to address these challenges. Following six years of lab and field research, it is now being applied commercially in the USA and across Europe.

Aim

The technology allows for wide dispersion of a Liquid Activated Carbon (LAC) in the aqueous subsurface. The medium has a dual function: it sorbs contaminants, quickly removing them from the mobile phase; and provides a high surface area matrix favourable for microbial colonisation and growth. By combining sorption with bioremediation in a single solution, risk reduction in the groundwater pathway can be achieved in days and contaminant destruction can be secured to stringent targets (low part per billion range) within weeks, with no intervention post application.

Field data confirm the lab tested wide-area dispersion, which showed more than 90% dissolved-phase concentration reductions secured at initial post-application sampling, increasing to more than 99% reduction within two months for both chlorinated solvent and hydrocarbon species alike. Laboratory data confirm post-sorption degradation enhancement, describing a significant increase in the rate of contaminant destruction in biotic matrix systems compared to abiotic matrix and biotic non-matrix controls.

Conclusion

The in-situ technology is particularly suited to the management of large, diffuse spreading plumes, and for deep, low concentration plumes in complex geologies. It is being used to inhibit spreading of contaminant plumes, protect sensitive receptors, and prevent contaminant migration across property boundaries.

Commercial project case studies will be presented to build upon lab and early field results and the technology's benefits, limitations and potential wider applicability will be discussed.

The CORE platform for lean, cost-effective and safe in situ and on-site remediation of mixed matrix multi contaminations

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Background

Development of remediation technologies has during past decades focused on basic research of biochemical and chemico-physical degradation (and extraction) of various major (and novel) contaminants. The seeming goal has been to develop more understanding for field scale biological and chemical in situ and on-site remediation. The development of technologies necessary for applying this basic knowledge has not significantly advanced since unified dimensioning and process configurations for pump and treat and soil vapor extraction were developed in the early 1990's.

Aim

The aim is to present in-depth the new CORE platform for in situ and on-site remediation and explain the possibilities of a unified process platform for multi-method remediation.

The CORE is a new technological platform developed by Doranova Oy, a remediation specialist company with over 20 years and 1.000 projects in experience. The CORE is specifically designed for soil and groundwater remediation. It consists of a selection of modules, each designed for a specific remediation task, ie. DNAPL separation, colloids filtration, air stripping, photo-chemical oxidation, chemicals or nutrient injection, etc. The platform allows for reconfiguring the remediation processes via automation, allowing to operate a single unit with different remediation processes ie. pump & treat, soil vapor extraction, chemical oxidation, bioremediation, etc. A single unit can manage different processes simultaneously, on single or multiple targets, and in series or parallel.

Thought it is fundamental in remediation to understand the underlying biochemical and chemico-physical processes, it is likewise important to have the technologies and tools available that allow for lean, cost-effective and safe deployment and operation of full scale field remediation.

Conclusion

The presentation describes the new CORE platform for in situ and on-site remediation and discusses how lean and cost-effective field remediation deployment can facilitate new industry knowledge on full scale remediation of mixed matrix multi contaminations, provide advancements in site data monitoring and increase HSEQ. To make in situ and on-site remediation more feasible in the Nordics, Baltics and globally, besides needing knowledge on opportunities, we need tools that can help us bridge those opportunities. The CORE is a new Nordic innovation that can do this and help achieve more sustainable remediation practices.

INNOVATIVE TECHNIQUE FOR THE REMOVAL OF PFC

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Background

Per- and polyfluorinated chemicals (PFC) are a large group of manufactured compounds that were widely used in household and industrial products. Furthermore, as part of aqueous film forming foams (AFFF) PFC played an important role in the tool box of firefighting brigades and saved certainly many lives. Locations where AFFF or Class B foams were repeatedly used are for example fire training areas on airports. In recent times it was possible to detect PFC in soil and/or ground water at those places. Due to their chemical properties PFC generate extended plumes in the ground water on many sites in Europe. Recent studies have shown that certain PFC may have a negative impact on people's health (eg possibly kidney cancer) but further research is required.

Aim

As a result of their chemical properties PFC show a very limited adsorption rate when contaminated ground water is pumped through activated carbon vessels. Nonetheless this is the most common treatment technology so far for removing PFC which are dissolved in the ground water on a contaminated site. Therefore, it had been the target to develop a tool that is able to improve the efficiency of a treatment plant and that can lower the corresponding operation costs. Such a tool got developed, modified and then successfully tested in a lab scale first at different levels of PFC contamination in water samples. Afterwards this product went for tests in the field on two airport sites in Germany. The background of the contamination on these sites had been a fire training area on one site and an airplane crash on the other. Based on the normal configuration of a P&T-system that works with GAC it is required to add a pre-treatment unit that consists of a dosing unit with reactor (stirrer) and a sedimentation tank that is equipped with a sludge removal system. In both projects this test unit was operated continuously at flow rates between 0,5 and 1 m³/hr. The PFC concentrations (13 compounds) in the contaminated ground water showed variations between about 23 and 45 µg/l on site 1 and between 300 and 700 µg/l on site 2. Elevated concentrations of dissolved iron (>20 ppm of Fe-II) had been observed on site 2. For achieving proper data, it was agreed to run tests on both sites for a period of 2 to 3 months in 2015. Changes in the flow rate during that time had been associated with variations in the PFC concentrations which again required adjustments in the dosing rates of the substance (PerfluorAd) that removes the PFC. These modifications had allowed to operate the test plant under different conditions.

Conclusions

One of the results of the tests had been that it is more challenging to remove PFC at lower concentrations of the contaminated ground water. And in addition to this the different compounds of the PFC group have shown varying removal rates. But nonetheless it was possible to remove more than 70% of the PFCs as an average value during that test in that pre-treatment unit on site 1. Performance peaks on single days achieved about 88% removal rate. On site 2 the PFC concentrations in the ground water had been much higher and that resulted in an even better performance. The removal rates for PFCs reached 95%. Based on these results a full-scale treatment system has been installed on site 2 in the meantime. The installation of that pre-treatment unit has lowered the operation costs of the treatment plants.

Remediation of residual explosive concentrations in groundwater

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Poster presentation

Background

Recently residual explosive concentrations of 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitroperhydro-1,3,5-triazine (RDX, also referred as hexogen) and Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX, octogen) has been identified in soil and groundwater in military explosives training ranges and impact areas administered by the Finnish Defence Forces. The military training areas are usually located on sandy, permeable soils which are often also classified as important (class I or II) groundwater areas. The discovery of explosive residues in groundwater has initiated research by Finnish Defence Forces in order to investigate the existence of explosive concentrations in soil and groundwater and to define remediation objectives for contaminated areas.

Aim

The purpose of this study is to collect information about explosives characteristics, migration and fate in groundwater. Also degradation and transformation of TNT, RDX and HMX as well as the fate of transformation products are largely unknown and will be assessed. The aim here is to test effectiveness and applicability of available and promising (based on literature review) groundwater treatment methods to assess possible utilization of the methods in future remediation of contaminated sites. Due to availability of applicable equipment, the groundwater treatment methods tested are based on pump-and-treat approach. Based on prior knowledge of explosives-contaminated process water treatment, possible options for groundwater treatment include degradation of the contaminants by UV light or removal of the explosive residues by granular activated carbon (GAC). Also the applicability of reverse osmosis process in removal of contaminants will be tested.

Conclusion

The study has been started by literature review and the analysis of the suitable methods is ongoing. The identification and site characterization of the possible contaminated sites among training areas has been initiated by Finnish Defence Forces and laboratory results from the planned test site are available. The research will be finished during summer 2016 and the results are available by autumn 2016. The aim is to achieve information for possible full-scale remediation projects in the future.

Field testing of a novel high-pressure ozone injection method for remediation of chlorinated solvent source zones in fractured limestone.

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“Poster presentation”

Background

Deep lying source zones (i.e., more than 40 meters below ground surface (m bgs)) in fractured limestone are often remediated by pump & treat (P&T) methods. Given the long duration (often more than 50 years) and resulting high operating cost of implementing P&T remedies in fractured bedrock, alternative methods are needed for addressing these source zones. The longevity of these source zones is driven by the effects of the long back diffusion time from the bedrock matrix into the fracture water, the quasi-static water in the fractures and the uneven distribution and sizing of the fractures in the matrix. As an alternative to P&T our objective was to use high-pressure in situ chemical oxidation (ISCO) with ozone. Initial testing of a novel high-pressure ozone injection system (i.e., more than 5.5 bar (80 psi)) was performed at a shallow fractured limestone site. At the Oelsemagle site (shallow site) in the eastern part of Denmark the subsurface close to the water table is contaminated with low levels of tetrachloroethylene (PCE) (i.e., 100 to 4500 µg/L), after the main spill has been excavated, and the depth to contamination is approximately 5 - 9 m bgs. The geological setting is glacial fractured bryozoan limestone, and the site had been characterized in detail during earlier investigations, which made this a good location for initial ozone system development. The primary goal of the testing at the shallow site is to inform the implementation of high-pressure ozone injection at another site in southern Denmark, where a deep lying PCE source is present in a similar geologic formation (deep site).

Aim

Testing at the shallow site consisted of ten injection wells where both a combination of air and ozone was injected as well as water extracted from downgradient. The gas mixture was delivered to the subsurface through a 15-cm long stainless steel diffuser installed in the bottom of a 5-cm stainless steel well screen. Ten wells were installed with lateral spacing of 10 meters. Nine wells were screened from 8.5 - 10 m bgs; one well in the center of the hotspot was screened from 18.5 – 20 m bgs. Water was pumped from one downgradient extraction well and re-injected into the ten injection wells simultaneously with air/ozone sparging. Injection pressure was monitored online and automated pressure compensation allowed consistent injection flow rates for individual wells despite varying back-pressures. Injection operated with a preprogrammed sequence, creating an oxidizing front, flowing with the natural gradient in the fractures. To extend the radius of influence (ROI), water was simultaneously injected into the injection wells with air/ozone gas. This resulted in aqueous and gaseous transport into the fractures, thus extending the radius of injection (ROI). At the shallow site, injection pressures up to 7 bar (100 psi) were observed, only limited by injection well back-pressure.

Conclusions

Testing at the shallow site consistently showed a ROI in the fractures of 15 meters with some locations achieving an ROI of 20 meters. These ROI values are particularly important design consideration considering the high cost of drilling at the target deep limestone site. This means that we are able to install injection wells with a 15 m spacing. Initial water samples taken during the injection period showed both consistent degradation and some upward trends of PCE. Desorption of contaminants was expected. We also see continuous decrease of primary contaminants in the source area as well as falling levels in the source-near plume.

IN-SITU REMEDIATION OF RETAIL STATION IN DENMARK WITH INNOVATIVE INJECTION METHOD (TRAP&TREAT® BOS200®) AND SITE CHARACTERIZATION PROCEDURES

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Background

A 12-15 m³ gasoline spill was discovered in 2003 from a leaking fuel supply pipe in the dispenser area at a main retail gas station outside Copenhagen (Denmark).

Site characterization works and remedial efforts by means of Skimmer Pumps, Pump&Treat (P&T) and Soil Vapor Extraction (SVE) system have been conducted from end of 2003 up and until 2012. Previous environmental investigation works were conducted at the site from the early 1990s. No main improvements to site conditions had been achieved.

Local geology consists of glacial till, boulder clay from upper soil to approximately 12 m bgl. An uneven layer of weathered limestone is present above the competent limestone formation which starts at approximately 13-14 m bgl. Groundwater is found at approximately 10 m bgl. Presence of Light Non Aqueous Phase Liquid (LNAPL) was observed across a large area.

In March 2012 a pilot test to assess effectiveness of Trap&Treat® BOS200® injection was conducted in conjunction with a full scale Remedial Design Characterization (RDC) event. During the pilot test approximately 4,000 kg of BOS200® were injected across an approximate 100 m² area. 25 Membrane Interphase Probe (MIP) points sided by approximately 15 soil core locations were conducted during the RDC event. This allowed creating a solid 3D contaminant mass model assessing the total contaminant mass present on site.

Aim

After negotiations with client and authorities on how to best conduct the full scale remediation in order to minimize site downtime period, the injection works started in October 2014 and were conducted over 2 phases of work (3 months each). Injection works were completed in May 2015.

During the injection works approximately 73,000 kg of BOS200® were injected in the subsurface from depths varying from 4-6 m bgl to approximately 13-14 m bgl. A total of 285 injection points were completed over an approximate total surface of 1,200 m².

Targets of the remediation were to achieve sustained contaminant mass reduction in the boulder clay (1-2 orders of magnitude reduction in dissolved phase concentrations), removal of LNAPL at the site and protection of limestone aquifer (impacted due to poor P&T installation and operation). 10 selected / agreed monitoring wells were used to set baseline contaminant (Benzene) concentrations and monitor over a quarterly basis the injection performance. Site boundary and off-site monitoring wells were used to monitor any possible contaminant migration outside the remediation area.

Conclusion

The detailed RDC works (allowing to delineate lateral, vertical extent and mass of the contamination) allows to design the injection of BOS200® in such a way to achieve optimal distribution of the product. The Trap&Treat® product allows achieving contaminant trap and treatment (biodegradation) functions with only one injection and one product. Remedial works can be conducting minimizing active site closure time.

9 months after injection completion a 90% average dissolved phase reduction throughout the selected monitoring wells and LNAPL removal has been achieved. Mass reduction continues to be observed through the downward trends in groundwater dissolved concentrations, as a results of the BOS200® product.

Quarterly results (part of a 5 years monitoring plan) are constantly presented to both client and local environmental authorities to continue monitoring the remediation performance until a No Further Action letter will be granted.

Case study: Low cost In-situ remediation on oil contaminated soil

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Background

The area Preem 2 in Karlstad is an oil depot that was demolished 2007 - 2008. Since 2008, Sweco has done a number of site investigations to determine the specific geology, hydrology, contaminant type and level of contamination. The investigations showed that an area of 21 000 m² where contaminated from 0-3 meters below ground level, in both soil and groundwater representing a total contaminated soil volume of 64 000 m³. The site investigations resulted in data that was used as a base for planning the full-scale remediation work done by RGS 90 Sverige AB.

Aim

RGS 90 implemented a full-scale In-Situ remediation in spring 2013, using the remediation methods Biosparging and Bioslurping. 213 Biosparging wells and 40 combined Biosparging-/and Bioslurping wells where installed within the area. The Bioslurping wells where installed where free phase hydrocarbons was located. The method Bioslurping extracts the free phase oil and treats both the soil, unsaturated zone, of volatile and semi-volatile organic contaminants by creating a mass flow using negative pressure. The method Biosparging was used to treat volatile organic contaminants around the saturated zone by pushing air into the ground to treat oil pollution and to favor the aerobic biodegradation process.

Performance monitoring was done in 15 monitoring wells located within the area, which included field testing of the pore gas concentrations every 3 weeks and sampling of groundwater every 3 months.

Conclusion

The system was originally designed to operate for 20 month. It is still in service in app. 20 % of the original area with an extension of 8 month in that area. During 6 month of the originally planned period the use of metal filters in the Biosparging wells did not work as planed since the metal wells got clogged with rust, and new plastic wells had to be installed to get efficient remediation effects.

The contaminated area has decreased and now only 59 Biosparging well are in operation. The monitoring shows that all the free phase in the area is gone and there are only 3 of 15 monitoring wells that are showing contamination levels exceeding the clean-up goals. Using the in-situ methods, including a minimal excavation in the source area around the oil containing wastewater pipes, a minimum of 80 000 kg oil product has been removed from the area. The In-situ remediation has to date cost 70 sek (7 euro) per ton contaminated soil.

The remaining low levels of contamination indicate that clean-up target will be achieved in the second quarter of 2016.

Innovative Formulations for Reductive Adsorption and Precipitation of Heavy Metals using Elemental Iron, Iron Sulfides, and Related Reactive Minerals

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Background

New and innovative applications of *in situ* chemical reduction (ISCR) have been developed for treatment of heavy metals. *In situ* chemical reduction has been broadly applied to treatment of soil and groundwater contaminated with chlorinated organics. The mechanisms involved in such applications are now well understood and widely recognized in the environmental remediation community. ISCR can be defined as a category of *in situ* soil and groundwater remediation technologies in which treatment occurs primarily by chemical reduction of contaminants, and mediated primarily by abiotic processes.

Aim

More recently, it has been recognized that innovative forms of ISCR can be very effective for removal of soluble heavy metals from soil and groundwater. The major groups of reductants operative in ISCR treatment of heavy metals in soil and groundwater include (a) elemental or zero-valent iron (ZVI), (b) minerals that derive their reducing power from Fe^{+2} (magnetite and ferruginous clays), (c) minerals that derive their reducing power from reduced S^- or S^{-2} either alone or in combination with Fe^{+2} (iron sulfides), and (d) organic matter containing redox-active functional groups (quinines). A significant advantage of the ISCR approach is that it can be effective in applications where both chlorinated solvents and heavy metals must be treated.

Conclusion

The authors will present a survey of ISCR materials and mechanisms as applied to treatment of a wide range of common heavy metal impacts found in soil and groundwater. Content will focus on the evolution of scientific concept through 2 years of bench-scale testing, followed by 1 year of field pilot and current full-scale application results in diverse geographies, including Europe, China and North America.

Case study: Combined Treatment Design for Remediation of Chlorinated Solvents

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Background/Objectives. A former dry cleaner site in Värnamo, Sweden, is contaminated with chlorinated solvents (PCE, with breakdown products) at depths of 0-35 mBGL in an area of approx. 40 000 m². A municipal drinking water abstraction well is located 450 m southeast of the site, and is being impacted with low concentrations of chlorinated solvents (particularly cis,1-2-DCE and TCE). In order to protect the groundwater abstraction well, a hydraulic containment system of four pumping wells have been located 20m, 45m 55 and 100 m from the source area, pumping out and treating 200m³/day. A source zone treatment comprising in situ Enhanced Reductive Dechlorination (ERD) and Multi-Phase Extraction and Soil Vapour Extraction (MPE/SVE) was then proposed to remove and prevent the secondary source from continuing to impact the groundwater. Concerns were raised that the MPE/SVE and the pumping system would not be compatible with the proposed ERD treatment, however to date, one year of monitoring show that the ERD treatment is working well, despite the nearest pumping wells are being negatively affected through biofouling.

Approach/Activities. The remedial strategy finally selected for full scale remediation comprised SVE/MPE in combination with reductive dechlorination. SVE/MPE is used in the unsaturated zone, ERD is used in the low permeable saturated zone using controlled release injectable substrates (HRCTM) – targeting high levels of contamination including DNAPL. The offsite receptor is protected by high volume pump and treat, which will ultimately be phased out, once the source area treatment is completed. The site presents many challenges to be accounted for in the integrated design; being located above a loop in the River Lagan, part of the site is formed of a steep unstable slope. Here implementation has been completed through multi-level directional drilling. The geology is highly heterogeneous vertically, comprising of sandy-gravel 0-8 mBGL, underlain by a low permeability saturated clay 8-12 mBGL, which is acting as an aquatard, and contains high levels of contamination including DNAPL. Under the clay is a fast-flowing, highly permeable coarse gravel 12-35 mBGL, which is carrying a small portion of the chlorinated solvents beyond the site boundary. The contaminant concentrations also have a large range; from 100-2000 mg/kg in the unsaturated zone and 10-100 mg/l (DNAPL) in the clay, hence treatment type and dose have been carefully formulated and targeted.

Results/Lessons Learned. To date, this site has shown that MPE and SVE can be used in conjunction with in situ ERD using injectable controlled release substrates in order to provide mass reduction in the unsaturated zone, whilst effectively establishing the required reducing conditions in the groundwater. By altering the drilling technique, this site demonstrates how injection can be completed in difficult locations, i.e. steep river-side slopes, and that directional drilling can be cost-effectively used for injection work. The results to date, show that ERD treatment can be effective in low permeability zones and where DNAPL is present. This site also shows that pumping downgradient of ERD treatment can lead to complications, as the soluble organic acids produced by the substrate are drawn to the abstraction wells, where iron- and bio-fouling can affect the function of the well. The problems that winter conditions have caused and the innovative solutions to overcome them will be addressed specifically.

MITIGATION OF PROPYLENE GLYCOL EMISSIONS TO GROUNDWATER AND SOIL

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Background

Propylene glycol based deicing agents are used at airports to remove ice and prevent ice accumulation into airplanes. Propylene glycol is readily biodegradable both aerobically and anaerobically but it has been noticed to migrate into groundwater (Greco et al., 2012). Currently propylene glycol emissions are collected and treated at municipal treatment plants. More information is needed about mitigation measures to prevent propylene glycol emissions into ground water and soil.

Aim

The objective of current study was to study whether low cost materials can improve propylene glycol degradation in soil and decrease its migration into groundwater and soil at low temperatures. The low cost materials were chosen based on literature survey and small scale laboratory experiments as well as technical parameters and current use at Finnish airport structures. Experiments were carried out in two pilot-scale temperature controlled lysimeters (height 3 m, radius 50 cm) operated at -5 to 20 °C, i.e. simulating winter, spring and summer conditions to compare control lysimeter and amended lysimeter. Deicing agent was mixed with flake ice in order to simulate snow and added on top of the soil and/or amendments. The purpose was to find out whether addition of peat and blast furnace sand can mitigate propylene glycol emissions.

Conclusion

Lysimeter leachate formation and migration of propylene glycol into lysimeter leachate were minimal when the soil was frozen. Biodegradation of propylene glycol was detected as formation of its degradation products in both lysimeters after the soil temperature had increased above 0 °C. However, comparison of results from control lysimeter and lysimeter amended with peat and blast furnace sand revealed that the amendments did not improve biodegradation of propylene glycol nor decrease its migration into lysimeter leachate.

EFFECT OF ELEVATED TEMPERATURE ON CIS-DCE DECHLORINATION INCUBATED WITH MULTI-ELECTRON DONOR COMPOUND

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Abstract

Recently, thermal-treatment-enhanced biostimulation is a promising remedy for completely cleanup of PCE and TCE contaminated sites. This research aimed to address the optimal concentration for a multi-electron donor compound (MEDC) which is composed of rapidly- and slow-fermenting electron donor compounds and investigate elevated temperature effect on ability of *Dehalococcoides* (*Deh*) spp. dechlorination and *bvcA*, *tceA* and *vcrA* genes abundance. For optimal MEDC concentration experiment, no evident *cis*-1,2-dichloroethene (*cis*-DCE) dechlorination difference was observed at 15°C as MEDC concentration increased from 50 to 500 mg/L. Whereas the optimal MEDC for *cis*-DCE dechlorination seemed to be 300 mg/L at 30°C. In order to confirm this result, *cis*-DCE dechlorination incubated with 200 and 300 mg/L at 15°C and 30°C was repeated. Results indicated that regardless MEDC concentration, *cis*-DCE and vinyl chloride (VC) was complete dechlorination at 30°C within 24 days. However, *cis*-DCE dechlorination incubated with 300 mg/L of MEDC was more rapid than incubated with 200 mg/L. *cis*-DCE dechlorination was complete at 15°C within 51 days incubated with 300 mg/L of MEDC, however, VC was residual in culture with 200 mg/L of MEDC. *bvcA* was undetectable in this study. At 30°C, *tceA* and *vcrA* genes abundance peaked on day 21 and then decreased. *vcrA* and *tceA* gene abundance increased till 51 days when MEDC concentration was 300 mg/L at 15°C, however, *vcrA* and *tceA* gene abundance fluctuated when MEDC concentration was 200 mg/L. In summary, optimal MEDC concentration was 300mg/L and MEDC concentration influence was negligible at 30°C. In contrast, MEDC concentration influence was significant at 15°C. These results indicated that elevated temperature was an efficient technology to enhance *cis*-DCE dechlorination at in-situ bioremediation site even under 200 mg/L of MEDC condition.

PRIORITIZING INVESTIGATIONS AND REMEDIATION – FROM REGIONAL SCALE TO CATCHMENT SCALE

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Background

In Region Zealand there is a great need for abstraction of uncontaminated groundwater for drinking water supply. More than 2700 possible polluted sites in the region must be tested for contamination and more than 700 polluted sites need further investigations and remediation in order to protect groundwater against pollution. It is a major task to find and remediate the sites that pose the greatest risk to groundwater and water abstraction before it's too late. This means that there is great need for prioritizing the task both at regional scale and catchment scale.

Aim

The aim is to develop a priority system at regional scale and catchment area scale for investigation and remediation of contaminated sites in order to protect groundwater.

Conclusion

The region is divided into approximately 40 subareas based on groundwater mapping performed by the Danish Nature Agency. The scope of the task for each area is assessed and compared with the need for abstraction of groundwater and groundwater vulnerability. In this way subareas are prioritized into 5 groups on regional scale. Subareas with high need of groundwater abstraction and low cost of handling contaminated sites are given maximum priority.

Within each subarea all catchment areas are given the same priority. A risk assessment tool has been developed to assess the overall risk of all contaminated sites in each catchment area. The calculation is based on flux and biological degradation of contaminants and compared with groundwater extractions volumes in each catchment area. The results in the first two subareas (Slimminge and Almsgård) show, that only a small part of the polluted sites constitute a real risk to water supply. Concrete action plans are made for these sites that are typically polluted with pesticides or halogenated solvents. The majority of sites are polluted with oil and present a lower risk to water supply. These sites are downgraded and will not be handled until we are finished handling sites with real risk in all subareas.

NATIONAL RISK MANAGEMENT STRATEGY FOR CONTAMINATED LAND IN FINLAND

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Background

National strategies are one important instrument for governments to steer contaminated land management (CLM) policy by creating a comprehensive framework for the risk management of contaminated sites. Ministry of the Environment defined general objectives for soil protection in the report in 1998. In many ways the conclusions and recommendations of the report are out of date. Re-evaluation of the key objectives and the identification of development needs and principles became a topical issue. There was a need for a comprehensive policy framework for promoting sustainable contaminated land management in Finland.

Aim

The main aim of the PISARA working group appointed by the Ministry of the Environment (from October 2014 to October 2015) was to define a future vision, main goals and principles for a national CLM policy. In addition, the strategy should contain recommendations for policy means and instruments together with a plan for the organization of the risk management of contaminated land areas in Finland. The task was divided into the following actions:

- defining objectives and goals for different CLM policy fields,
- making recommendations for policy means and instruments to achieve the policy goals,
- presenting a groundwork proposal concerning the reform of the State Waste Management System for contaminated soil sites and
- preparing The National Investigation ja Remediation Programme.

The preparation process included close interaction with various stakeholders e.g. the working group organized workshops, meetings, interviews and commentaries. Thus various stakeholders were engaged in establishing a comprehensive view of the current state. Based on this, the working group formulated the goal, objectives, and recommendations for policy means and measures.

Conclusion

The main aim of the strategy is: Significant risks of contaminated land to human health and the environment are managed in a sustainable way by the year 2040. This goal can be achieved by meeting the following six objectives:

- Risk sites are identified, investigated and remediated systematically.
- Spatial planning and risk management in contaminated land support each in order to achieve sustainable and comprehensive solutions.
- Data management systems support planning and decision-making in a user-friendly way.
- Remediation methods are cost-efficient, save natural resources, minimize adverse environmental effects and promote circular economy.
- Procedures are interactive and the roles, responsibilities, and liabilities of the actors are explicit.
- Practices and communication are open, transparent, and interactive.

The strategy contains recommendations for policy means and measures to achieve the objectives in an efficient and feasible way. The responsible actors for the measures and actions are identified as well. The purpose of the National Investigation and Remediation Programme for Contaminated Sites is to identify significant contaminated areas and promote research on these and the implementation of necessary risk management measures. In addition, the group prepared a proposal on main principles according to which the reform of the State Waste Management System work can be started.

The Programme includes also The Pilot Project implemented in 2016–2018 as a part of the key projects of Prime Minister Sipilä's Government programme. The aim of The Pilot Project is to enhance the development and introduction of sustainable risk management methods.

NATIONAL SOIL GEOCHEMICAL DATABASE - TAPIR

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Background

In Finland, reliable geochemical baselines, referring both to the natural geological background concentrations and the widespread anthropogenic input of substances, are needed in many environmental applications. The main use is in assessing soil contamination in accordance with the Government Decree (214/2007) while the legally prescribed threshold values can be replaced with regional geochemical baseline values. Reliably defined geochemical baseline values enables also to determine case-specific guidelines for soil contamination assessment when prescribed guideline values based on ecological risks can be modified accordingly. This give tools to better assess remediation needs as well as to choose the best available remediation technique. Based on national guidelines on the exploitation of excavated land by the Ministry of the Environment, the exploitation and re-deposition of excavated land applies information on geochemical baseline. For example aggregates with elevated background concentrations are not considered contaminated if there is plan for future use of the material. However, they can be exploited or placed only in areas with similar or higher regional geochemical baseline concentrations. In addition, data on baseline state of soil is applied in environmental impact assessment and environmental baseline surveys. Environmental authorities, land use planners and policy makers need reliable information on distribution and concentration levels of harmful elements especially in urban and sub-urban areas for construction, aggregate production and water supply purposes as well as for health and environmental risk assessment.

Aim

Geochemical surveys have been carried out since the 1930s in Finland. Today, geochemical background information is available from national and regional geochemical mapping surveys, as well as from targeted geochemical baseline surveys, from which geochemical baseline mapping of urbanized areas has had a special focus on environmental applications and land use planning. In order to provide access to existing information on geochemical baselines that are based on reliable mapping and analysis methods, a national soil geochemical baseline database, TAPIR, was established. Web-based map server interface provides an easy access to the regional baseline values and it also allows calculating regional geochemical baseline values for a specific area in question. TAPIR is publicly available via the Internet both in Finnish and English languages (<http://gtkdata.gtk.fi/tapir/>)

Conclusion

The national soil geochemical baseline database, developed in co-operation between Finnish geologists and the environmental authorities, provides scientifically sound, easily accessible and generally accepted information on the geochemical baseline concentrations, thus contributing to rational and transparent decision-making.

The Challenge of Assessing and Anticipating Environmental liabilities in a changing World.

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Background

Assessing environmental liabilities and environmental risks is the preoccupation of environmental professionals in industrial corporations, insurance companies, contaminated land real-estate developers and governmental agencies. Making an assessment, automatically means setting endpoints and target levels in reference to health or ecological issues. In developed economies these endpoints will be imbedded in a legal framework. These legal frameworks themselves are quite rigid over time, but scientific insights can change and consequently endpoints in laws & decrees can change over time. In emerging economies, more challenges arise : lack of proper legal framework, the shortage of experienced professionals and no proper governmental partnership to determine endpoints.

Aim

The absence of endpoints is a problem in light of the increasing pressure in emerging economies to act on environmental issues. So how to approach all these environmental risk and liabilities under changing circumstance ? Is there an existing, universal approach or framework ?

Conclusion

In our research we found only one enveloping approach. Accountancy rules under GAAP. Accountancy rules like GAAP offer a framework for assessing environmental liabilities. The basis approach here is that the risks need to be tangible and real. As a basic guideline, terms like 'recognition' and 'measurement' are respectively defined as step 1 'recognizing a real issue' and step 2 'measuring the extent of the issue'. What is also interesting about the GAAP rules is, that it takes into account market circumstances and the qualifications of environmental practitioners. GAAP rules recognize that a functioning market place with reliable market partners and qualified practitioners is a condition for real Fair Value assessment of any environmental liabilities. 5 real life cases are explained and an insight is given on the in's and out's of these cases under study. Additionally, it is illustrated how the GAAP framework can work for any environmental profession in assessing liabilities anywhere in the world.

Radon Gas – Risk Awareness and Response in the UK

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Background

A report by the UK's public health agency in 2009 estimated that radon is a cause in over 1,100 lung cancer deaths each year in the UK. A radon Action Level for housing of 200 becquerels per metre cubed (200 Bq/m³) has been adopted in guidance, and where this is exceeded, a Target Level of 100 Bq/m³ is recommended. The 100 Bq/m³ level is the standard to be achieved for protective measures in new buildings. In the workplace, the Ionising Radiations Regulations 1999 (IRR99), specify an action level of 400 Bq/m³ (average radon level, measured in the winter months), above which action is required to reduce or manage radon levels.

Aim

The aim of this presentation is to summarise UK experience in the regulation of radon gas and the promotion of public awareness. The presentation will discuss the UK approaches to radon hazard mapping and compare these with practices in other European jurisdictions.

The UK's approach to implementing the BSS Directive (basic safety standards for protection from ionizing radiation: Directive 2013/59/EURATOM) and Directive 2013/51/EURATOM (protection of the public with regard to radioactive substances in water) will be discussed and a review of technologies commonly adopted to address radon gas issues in the UK will be presented.

We will discuss Ramboll Environ's experience in advising landlords and occupiers of existing commercial properties on radon issues and will consider how public and corporate awareness and adoption of good practice can be improved.

Conclusion

While radon gas has significant known health impacts, perceptions of risk and low awareness of the hazard represent barriers to achieving protection of health. This presentation will discuss how the risks from radon to owners and occupiers of commercial properties can be better identified, managed and mitigated.

ECOLOGICAL RISK ASSESSMENT OF CONTAMINATED SEDIMENTS. METHODS EXISTS BUT REGULATIVE STEERING IS WEAK

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Poster presentation

Background

Sediments can act as a sink for chemicals through sorption of contaminants to particulate matter, and may act as a source of contaminants to deposit and particle feeders or dissolve back to the water phase by desorption. Apart from the prospective risk assessment (RA) of the man-made chemicals (e.g. in REACH), the retrospective site-specific assessments conducted on contaminated areas as diagnosis tools in the identification of ecological effects is still undeveloped in many countries. This is mainly due to absent of steering law although guidance is available in relevant REACH and EU documents.

Successful RA of contaminated sediments requires knowledge on exposure and effects. Methods able to quantify exposure and estimate the risk for metals and hydrophobic organic contaminants are available but the progress in the ecological risk assessment of sediments needs recognition of the problem, understanding of the processes and regulatory, or even, political steering.

Aim

This presentation aims to describe tiered approach for assessing contaminated sediments, to promote derivation of the environmental quality standards (EQS) followed by site-specific assessment and to present recent advancements in exposure and effect assessment in the toolbox of the Finnish Environment Institute.

Conclusion

The main reasons for the lower status of the sediments compared to surface water RA are much more complex environment and the lack of simple methods for assessment. This has probably hindered the development of steering by the law although recent directive (2013/39/EC) allows Member States the possibility to derive environmental quality standards for the priority substances in sediment compartment. The derivation of reliable EQS values would need toxicity tests with several species at all trophic levels and calculation of species sensitivity distributions. The application of the EQS would only be the first tier as the bioavailability for organic contaminants and metals, is very site-specific. New, relatively simple approaches to account for bioavailability are modelling and direct measurements of the pore water concentrations with the passive samplers. These can then be translated to tissue concentrations assuming the pore water is the main route for accumulation, which connects environmental concentrations to tissue residue based effect assessment.

Investigation Strategies and Methods in Order to Determine Vapor Intrusion Pathways

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Background

Every year a number of project are carried out in Denmark to eliminate or at least reduce VOC contamination of indoor climate of existing houses due to vapor intrusion (VI). However experience shows that for many projects the measures carried out couldn't reduce the vapor intrusion sufficiently. Often because one or more vapor intrusion pathway has been overlooked or underestimated.

One way to overcome this problem is to design the measures more robust. However in Denmark we have a tradition to minimize costs by designing the measures to the necessary and sufficient level. This approach in turn requires that you have identified all significant pollutant sources and significant vapor intrusion pathways and pathways in the building.

To identify these pathways COWI has developed an investigation approach, using a variety of known investigation techniques including tracer gases fx CO₂, formid gas and radon, PFT tracer gas, low level continuous detectors, long-term measurements and fingerprint of the pollution/pollution composition.

Aim

In the talk, investigation approaches is described using three case stories, showing the techniques advantages, disadvantages and limitations.

The case stories illustrates the combination of investigation techniques used to obtain a conceptual understanding of the movement of air with in the building and air movement in and out of the building including VI. Cracks in the slap and cracks in basement walls are known as the main intrusion pathways, but other pathways such as drainage system, cavity walls and old unused chimneys can be significant pathways and has to be identified to gain the right conceptual understanding.

Building has a very inhomogeneous structure, with areas of high permeability as living rooms, stairwells and elevator shafts, but also cavities and fractures, and very low permeability barriers such as walls and floors separating compounds. This homogenous structure makes it necessary to think three-dimensionally when setting conceptual models for a building. The talk will give examples of how to design three-dimensional conceptual models for buildings, and how to illustrate the results in order to stay organized.

Conclusion

Understanding of air movement within and in and out of the building is necessary in order to give an accurate risk assessment of VI, but also to design the appropriate measures. To gain that understanding it is necessary to use a variety of investigation techniques and to use three-dimensional conceptual models. Hopefully talk will give inspiration to further development of the techniques described

THE EFFECT OF SOIL CONTAMINANTS IN INDOOR AIR AND SOLUTIONS FOR RISK MANAGEMENT

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Background

Soil contaminants effecting indoor air quality are often ignored in air quality surveys. They may originate from old landfills, soil fills, oil spill or other accidents. Landfills may also produce gases, which are explosive, smell badly or result in health risk. Hazardous substances originating from soil may transport to indoor air by diffusion or convection. To avoid risks, specific remediation and/or management procedures have to be designed that require many-sided expertise.

Aim

To control the risks and spread of soil contaminants, it is necessary to carry out site investigations to assess the level of hazardous substances in soil, ground water, soil vapour and indoor air. Designing sampling and analysis requires a specialist to gain reliable results. Based on the results, possible risks in current or future use of soil can be assessed. If the risks arising from contaminated soil or ground water can be significant, risk reduction methods have to be designed and applied.

Conclusion

Reliable analysis results, knowledge on present constructions or upcoming land use and an expert evaluation of possible risks are needed in assessing possible risks of soil contaminants in indoor air. The methods for environmental and construction material sampling are discussed in detail and possible routes for contaminants are evaluated. Site specific data impacts heavily on the outcome of risk calculations and its reliability and accuracy is a key parameter in risk assessment. Contaminant concentrations in indoor air of existing buildings can be measured, but several factors influence the outcome of the measurement and risk evaluation is always an important step. The reference values for indoor air in guidance given by Finnish authorities are not always risk based, which has to be taken into account in evaluation.

The risk management procedures differ a lot in existing buildings and on areas under construction. Passage of some contaminants can be blocked by encapsulation materials, changing air pressure and or ventilation parameters or with specific structures. For oil hydrocarbons, for example, there is no encapsulation material shown to block transport entirely. For areas under construction soil remediation below the level of significant risks is usually possible. With carefully designed risk management expensive soil excavation may be reduced.

FOLLDAL MINES – ASSESSMENTS OF REMEDIAL ACTIONS AGAINST HEAVY METAL POLLUTION FROM MINING ACTIVITIES

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Background

The Folldal mines in southern Norway were active in the period 1748-1968 with extraction of pyrite that contained copper, zinc and sulfur. The mining waste/tailings were dumped outside the mines. The centre of Folldal is built upon these tailings. Folldal mines, the surroundings and the remaining buildings are one of only a few technical-industrial cultural heritage sites in Norway.

Oxidation of sulfidic rock and tailings have caused drainage with low pH and high content of heavy metals – acid rock drainage (ARD). This drainage water leads to Folla, the river that flows through the centre of Folldal. Fish and other water-living organisms are not present in Folla from Folldal and 12 km downstream, due to the heavy polluted drainage water.

DMF was in 2003 given from the Royal Norwegian Ministry of Trade and Industry the imposition to reduce the amount of copper that reach Folla from the mines and tailings with 60-90 %, which means from 14,7 ton until 1,5-5,9 ton. Another goal is to reduce the concentration of copper in Folla from ca 50 µg/l to 10-15 µg/l. Several attempts have been done on collect ARD and clean the water before it reaches Folla.

Aim

NGI has in 2014-2016 carried out several investigations in minewaste, tailings, groundwater, drainage water, river water and sediments in Folla to find the main sources for pollution of Folla. The main source of ARD seems to be the tailings where ARD is being produced due to infiltration of water. This water is transported with channels and rivers to Folla.

Based on the investigations, all possible remediation alternatives (chemical/physical/natural cleaning of water, capping of tailings and remediation within the mines) are estimated in a cost/benefit aspect.

Conclusion

The recommended remediation alternatives are a combination of the following:

- Capping of mine waste and tailings. Dependent on the extend of capping, the goal of reduced transport of copper to Folla will be reached by 40-90 % .
- Natural neutralization and precipitation of drainage water on the river banks.

A Field Study of the Dissolution of Pb, Sb and Cu at Shooting ranges

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Background

Shooting range soils are impacted with Pb, Sb and at rifle ranges, also Cu. Since some of the shooting ranges are located on protected groundwater areas there is a risk that the metals deposited to the shooting ranges might be leached from the soil to the groundwater and even migrate to public water work wells. The need to characterize what is the true mobility of these metals in different environments is therefore critical.

Traditionally dissolution of shooting range metals has been evaluated using soil-water partition coefficients (K_d-values) from literature or using information from leaching tests (f.ex. US EPA Method 1312). K_d-values from standard look up values and K_d-values calculated from the above mentioned leaching tests vary within orders of magnitude. There are several reasons for this. As for example metal mobility may be dependent on the redox state of the metal, hence information of the metal mobility at in situ conditions is needed.

Aim

- 1) Evaluate the mobility of metals in actual environmental conditions of the sites, where the ambient temperature and humidity condition change as opposite to laboratory conditions.
- 2) Develop a simple testing device, lysimeter that uses a sufficient amount of soil to enable the testing of a truly representative sample from the test site and can be easily used the range operators.
- 3) Test how the geochemical conditions affect the mobility of shooting range metals.
- 4) Test the sorption of dissolved Pb, Sb and Cu to clean soil.
- 5) Test what is the amount of precipitation that percolates through the soil column i.e. the annual infiltration rate.
- 6) Test if an iron amendment in the soil would reduce the dissolution of metals.

Conclusions

- 1) The mobility of metals (Pb, Sb and Cu) was generally lower than the predicted mobility based on look up values from Finnish guidance.
- 2) The lysimeter can be easily build from common materials available at any hardware store and the operation of the apparatus is simple. The simple construction of the lysimeter allows it to be easily used at common shooting range sites.
- 3) The geochemical conditions (pH, TOC) varied but there could not be seen a clear relationship in the effect of pH and TOC the mobility of the tested metals.
- 4) Pb and Sb were effectively sorbed to clean soil that was tested on one site.
- 5) In average 83 % of the precipitation was percolated through the soil column to the lysimeter reservoir.
- 6) Metallic iron amended to soil significantly reduced the mobility of Pb and Sb, but did not have a clear impact on Cu mobility.

ANTIMONY IN SOIL AND GROUNDWATER AT SMALL ARMS FIRING RANGES

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Background

Up until 2014, site investigations at military small arms firing ranges (SAFR's) in Denmark have focused on lead as the primary contaminant of concern. However, studies of sampling and analytical practice in other NATO countries have identified antimony as a contaminant of possible concern at SAFR's. Initiated by the Danish Defense, The Danish EPA in 2015 defined a health-based soil quality criterion for antimony.

Prior to site remediation at six shooting range locations, the Danish Defense have analyzed soil and groundwater samples in order to assess the occurrence of antimony. The site investigations have provided information on the presence of both lead and antimony as critical contaminants at SAFR's. Subsequently, site remediation has been performed based on findings from these site investigations.

Aim

The aim of this presentation is to present recent studies on the occurrence of antimony in soil and groundwater at SAFR's in Denmark. The presentation will include:

- Information concerning projectiles and activities that form the basis for the occurrence of antimony at SAFR's.
- An overview of identified concentrations of antimony in soil and surface near groundwater.
- A correlation between the present concentrations of antimony and lead in top soil at SAFR's.
- A comparison - and subsequent recommendation - of soil sampling methodology, documenting the benefits of using Multi Incremental Sampling (MIS) instead of discrete sampling to estimate contaminant concentrations in source areas.
- Recommendations regarding chemical analyses for antimony in soil.

Conclusion

Site investigations, including discrete soil sampling and MIS-sampling, have identified antimony in concentrations up to 610 mg/kg DW. Concurrently, lead was present in concentrations up to 20,600 mg/kg DW.

In source areas antimony has been found in surface near groundwater in concentrations ranging from non-detect to 4 µg/l, thus indicating a very small potential for leaching of antimony to the groundwater. This corresponds to the K_d -based calculation of very low vertical transport times for antimony.

For characterization of average contaminant concentrations in soil it is recommended to use Multi Incremental Sampling as sampling methodology.

For chemical analysis of antimony (and lead) in soil it is recommended to use a combination of hydrochloric acid and nitric acid for sample digestion (Aqua Regina).

Microscale geophysics for characterizing complex hot spot areas – Comparison of three methods and the actual geology obtained from direct excavation

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Background

A rather large part of the northern hemisphere has quaternary deposits consisting of glacial clay till. The till often has a complex hydrogeological structure consisting of networks of fractures, sand stringers and sand lenses each contributing to a transport network where water, free phase and dissolved contaminants are transported from the surface and downwards. Understanding the nature and structure of these networks are crucial in developing conceptual models (CSMs) of the spreading of contaminants.

The toolbox used for characterization of the geological and hydrogeological structures typically consists of different kinds of soil borings, direct imaging tools like EC and MIHPT and different hydraulic/pneumatic tests. On larger scale, different geophysical methods have been used intensively in many years for different mapping activities with success, but most superficial methods have fallen short using it at a local scale for building CSMs. Due to that, research recently has been directed toward using these methods in different configurations and with more sophisticated data acquisition and processing trying to improve and optimize data collection.

Aim

In 2015 the Capital Region of Denmark initiated a small program where the objective was to identify potential methods that could track/delineate sand stringers/lenses of a thickness of 10 cm in a 10 m by 10 m by 10 m clay till volume. In late summer of 2015 it was decided to make a test field testing with three different between well geophysical methods, which had the potential to succeed. The actual test was carried out in November/December 2015. The overall objective was to make a proof of concept for the methods, comparing the results and interpretations with an excavation and measuring of the actual geology at the test site.

Conclusions

A test field with a size of approximately 150 m² was selected based on geology information obtained from borings down to approximately 10 mbg. The field was located near the digging front in a gravel pit west of Copenhagen. In the pit the geology comprises in general of a till clay with sand layers/stringers embedded down to 5-10 mbg. underlain by vast layers of sand and gravel. At the actual test location, the clay was 6-8 m thick. Three techniques were tested: Ground Penetrating Radar Tomography, Seismic Waves Tomography and In-Well DCIP Tomography on a 5-15 m scale. The interpretation of data are carried out by the participating universities at the time of the abstract production, initial data interpretation shows promising results. The pit front was dugged in a layer/staircase manner in order to get measures (size & orientation of layers) of the actual configuration of the embedded sand layers given a more complete picture than well logs. Considerations of economics and general applicability will be made based on the assembled results.

USING A POLYMER AS LINK FOR PASSIVE SAMPLING MEASUREMENTS ACROSS THE SEDIMENT-WATER INTERFACE TO QUANTIFY CHEMICAL ACTIVITY GRADIENTS

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Background

Passive sampling is increasingly recognized as a superior monitoring tool for nonpolar organic chemicals in water and sediment. Beyond monitoring, passive sampling offers opportunities to explore contaminant transport mechanisms in large water bodies; and the potential of these opportunities have yet to be fully exploited. Through the direct quantification of in situ freely dissolved concentrations (C_{free}) as measurement endpoint or, more accurately, measured concentrations in passive sampling polymers, passive sampling can provide a thermodynamic insight into contaminant dynamics in the multimedia environment, and across interfaces, as on a polymer basis measurements can be linked to chemical activity.

Aim

The objectives of our research were to (i) deploy a recently developed¹ sediment-water contaminant profiler in combination with passive samplers in the water column for a vertical mapping of the PCB, PAH and organochlorine pesticide contamination in the Inner Oslofjord, (ii) use different types of polymers and thicknesses as well as performance reference compounds to validate the obtained results, and (iii) use the data to study contaminant transport dynamics in sediments, across the sediment-water interface and within and across the benthic boundary layer.

Conclusion

Parallel deployment of different passive sampling materials in different thicknesses (polyethylene and silicone) proved to be a simple and effective tool to validate obtained passive sampling data. Advantages and disadvantages of using polyethylene and silicone in this type of assessment will be presented. Passive sampling across the sediment-water interface using the newly developed sediment porewater profiler in combination with passive sampler deployment in the water column facilitated a vertical mapping of the contamination and allowed a thermodynamically based assessment of contaminant fluxes.

¹Lin D, Eek E, Oen A, Cho Y-M, Cornelissen G, Tommerdahl J, Luthy RG. 2015. Environ. Sci. Technol. Lett. 11, 320-324.

APPLIED TREE CORING FOR LOCATING CONTAMINATED AREAS WITH CHLORINATED SOLVENTS

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Background

Site investigations are often time consuming and costly, which raises a demand for rapid and inexpensive screening methods. Research work has shown that phytoscreening by tree coring is useful for detecting soil and groundwater contamination with chlorinated solvents. The principle of the method is that subsurface contaminants are taken up by the tree roots and subsequently translocated to the stem. From the stem a small tree core sample can be collected, analysed by P&T-GC-MS and it will then reveal the presence of subsurface contamination. The method allows high-density sampling at low cost and time expense. Samples represent a relatively large soil volume due to the large root system and can be applied at most soil types including swampy and rocky areas.

Aim

The aim of this presentation is to demonstrate the commercial feasibility of tree coring during site investigations based on results from several case studies. Laboratory analysis of tree cores is now routinely available at several laboratories and can easily be implemented. Tree coring was applied as a screening tool at sites contaminated with chlorinated solvents. The sites included a village where two water supply wells were contaminated and the source was unknown, areas with difficult access (very dense vegetation and ramparts) and areas near surface water. Tree coring was applied in order to a) locate contaminated source areas and b) identify groundwater discharge zones to surface water.

Conclusion

By tree coring areas with ramparts and very dense vegetation were screened within a few hours, while other methods would have been unsuitable or would have required the removal of vegetation.

A village of app. 0,4 km² was screened in two days and the source of contamination was identified 200-290 m upstream the water supply wells.

Tree coring along streams indicated groundwater discharge zones where chlorinated solvent plumes discharged into the streams. These discharge zones were not in all cases pointed out by water sampling.

Based on the results from these three cases as well as several other contaminated sites we conclude that tree coring is a useful and diverse screening tool that allowed the optimisation of subsequent site surveys

Sediment traps in assessing the impacts of dredged material sea disposal

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Poster presentation

Background

Dredging of the seafloor is often a prerequisite of keeping seaways and harbours operational in the coastal area of Finland. This leads to a need to transport and dispose the dredged material, which in turn creates environmental concerns. There has not been as much research on the long term effects of sea disposal due to difficulties in observing material at the bottom of the sea and the difficulties in separating the effects of disposal from background conditions. The Finnish Transport Agency has initiated an R&D project in order to assess the effects on sea disposal sites and to define the preconditions for environmentally sustainable disposal projects.

Aim

The objective of this study was to gather research data to assess the impacts of dredged material sea disposal of compared to background conditions. The reliability and the applicability of sediment traps were also evaluated. The study was carried out by monitoring alterations in sedimentation in the surroundings of the disposal site. The study area was located in the Uusikaupunki archipelago, Southwest Finland. Research data was collected by using bottom-mounted sediment traps and automatic water quality and currents meters. The study included three monitoring periods, first prior to the major disposal operations, second during the disposal and third after the disposal operations. In order to define background conditions alterations in sedimentation was also monitored at two reference points.

Conclusion

Sediment traps proved to be a useful and a cost-effect instrument in assessing the impacts of sea disposal. The identified alterations in sedimentation corresponded well to the automatic water quality and currents measurements. The difference between replicate sedimentations samples was six percent on average. The main limitation of sediment traps is that they collect sinking particulate material only about half meter above sea bottom and thus fail to collect resuspended particles in immediate proximity of the sea bottom. During the disposal operations the impacts to sedimentation were recorded a maximum distance of 600 meters of the disposal site. No alternations of sedimentation due to sea disposal were identified in the last monitoring period three and a half months after the disposal operations.

EVIDENCE OF IN SITU BIODEGRADATION OF ETHYL *TERT*-BUTYL ETHER (ETBE) IN A FUEL-CONTAMINATED AQUIFER USING STABLE ISOTOPE TOOLS

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Background

Ethyl *tert*-butyl ether (ETBE) is a fuel additive, which is a frequently detected contaminant in soil and groundwater. The low odor and flavor thresholds in water of 1-2 µg ETBE L⁻¹ makes drinking water resources easily unpalatable. *In situ* biodegradation of ETBE has only scarcely been investigated at contaminated field sites.

Aim

The intention of this study was to prove and characterise the *in situ* biodegradation of ETBE in a fuel-contaminated aquifer using two stable isotope tools: i) compound-specific stable carbon and hydrogen isotope analysis (CSIA) and ii) *in situ* microcosms (BACTRAP®s) in combination with total lipid fatty acid (TLFA)-stable isotope probing (SIP). The BACTRAP®-approach was conducted for different hydrochemical conditions: (a) presence vs. absence of other petroleum hydrocarbons (PHs) as well as (b) under natural redox conditions vs. the influence of oxygen injection.

Conclusion

CSIA revealed insignificant changes in carbon isotope ratios (¹³C/¹²C) but the hydrogen isotope ratios (²H/¹H) for ETBE suggests biodegradation of ETBE along the predominantly anoxic contaminant plume. Ten months after CSIA, oxygen injection into the aquifer was conducted to enhance the biodegradation of PHs. Within the framework of this remediation measure, BACTRAP®s amended with ¹³C-labelled ETBE were exposed for 119 days in groundwater wells with various conditions to assess the biodegradation of ETBE by TLFA-SIP. Under all conditions, ¹³C-enrichment in TLFA provided clear evidence of *in situ* ETBE biodegradation. Our study highlights the applicability of the BACTRAP®-approach for evaluating ETBE biodegradation at contaminated field sites.

ASSESSMENT OF MICROBIAL POLYCYCLIC AROMATIC HYDROCARBON (PAH) DEGRADATION IN A CONTAMINATED AQUIFER USING IN SITU AND LABORATORY MICROCOSMS WITH ¹³C-LABELLED TARGET COMPOUNDS

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Background

Polycyclic aromatic hydrocarbons (PAHs) are among the most abundant environmental contaminants worldwide. Due to their toxic, mutagenic and carcinogenic effects to humans and animals, PAHs are pollutants of particular concern. Therefore, the effort to reduce their environmental impact is of paramount importance. The role of *in situ* biodegradation of PAHs is only partially understood, in particular due to the limited number of suitable monitoring tools.

Aim

The intention of this study was to assess the *in situ* biodegradation of four PAHs (naphthalene, fluorene, phenanthrene, and acenaphthene) in an oxic aquifer at the site of a former gas plant using an integrated approach comprising *in situ* and laboratory microcosms in combination with ¹³C-labelled PAHs as tracer compounds.

Conclusion

In situ microcosm (BACTRAP®s) were amended with either ¹³C-labelled naphthalene or fluorene and were incubated for a period of over two months in two groundwater wells located at the contaminant source and plume fringe, respectively. Subsequently, assimilation of the ¹³C-label from the ¹³C-labelled PAHs into microbial amino acids extracted from BACTRAP®s was analysed. Amino acids showed significant ¹³C-enrichment, thus providing clear evidence for the *in situ* biodegradation and assimilation of naphthalene or fluorene. In order to provide quantitative information on the PAH biodegradation, a laboratory microcosm was conducted. Groundwater and BACTRAP®-grown cells were used as inoculum and incubated under *in situ*-like conditions with ¹³C-labelled naphthalene, fluorene, phenanthrene, and acenaphthene as tracers. Mineralisation was quantified by analysing the formation of ¹³C-CO₂. Mineralisation rates of PAHs ranged between 17 µg L⁻¹ d⁻¹ and 1639 µg L⁻¹ d⁻¹. Based on our results, *Monitored Natural Attenuation* (MNA) was considered as potential management strategy for the investigated field site.

EFFECTS OF ACTIVATED CARBON ON PCB BIOACCUMULATION AND BIOLOGICAL RESPONSES OF *CHIRONOMUS RIPARIUS*

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Background

Activated carbon (AC) amendments have been studied as a new stabilizing method for contaminated sediments. The sorption efficiency of AC toward hydrophobic organic compounds (HOCs) has been shown in several studies. Recently the focus has been turned also to the possible secondary effects of the carbon amendments. Especially sediment dwelling organisms has been observed to be sensitive to AC amendments. Sediment dwelling organisms are present in many aquatic ecosystems and often form the basis of aquatic food webs, therefore these effects cannot be considered negligible.

Aim

The effects of AC amendment were studied with *Chironomus riparius* in a full life cycle test. The purpose of the study was to follow the effects of AC amendments on the transfer of PCBs during the metamorphosis from the larvae to the adult midges, and to study the possible secondary effects induced by AC.

Conclusion

AC amendment reduced the PCB concentrations determined with both bioaccumulation test and passive samplers. Additionally the PCB concentrations of midges emerging from AC treated sediments were reduced. Adverse effects were observed on the larvae growth and development, and morphological changes were seen on the gut wall microvilli layer. On the other hand, low dose of AC (0.5% sediment dw) slightly improved reproduction, survival, larvae growth and increased gut wall microvilli length in one of the studied sediments, indicating that AC amendment reduced the sediment toxicity by altering the bioavailability of the contaminants. Site specific characteristics are important when the remedial measures are designed to balance between effective contaminant bioavailability reduction and adverse effects of the amendments.

Keywords: Activated carbon, remediation, ecological responses, sediment
Preferred presentation format: poster

Active Geosynthetic Composites for subaqueous capping

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Background

Subaqueous contamination in harbors and water bodies close to former industrial sites pose a threat to the environment. The contaminants found at these sites have low solubility products and therefore stay in place causing a low but steady contamination of the water for a long time. The usual remediation technologies used in these cases are in-situ capping or dredging, dewatering and disposing of the sediments on a landfill. To run dredging operations, onshore support is required to dewater the sediments and if necessary also to treat the water prior to discharging it back.

In-situ capping can be an additional or an alternative operation to dredging. In this process sand is used to cap the contaminants in place isolating them from the water. To improve the cap performance active materials like bulk activated carbon can be added as first layer on top of the contamination. They do not only cap the contaminated sediments but also treat them. The type and amount of active material used depends on the type and concentration of contaminants. The problem with these two operations is that they include high installation expenses as the granular capping material sediments slowly to the ground and is put in order by divers. Also currents and underwater inclinations complicate the installation. Especially when using bulk active materials a high coefficient of safety needs to be applied to ensure a minimum active layer thickness throughout the entire cap. On the other hand the thicker the cap is the more impact it has on ship transport as the navigable depth is being reduced.

Aim

This study outlines that the combination of active materials and geotextiles can be an additional solution for the treatment of subaqueous contaminated sites. A composite product of geotextiles and active materials can be used for in-situ active capping. The combination ensures easier installation and less needed material as a constant layer thickness can be guaranteed independently from water currents and inclinations. This also reduces the impact on the navigability of the water body. The study also illustrates the performance of different active materials on different contaminants.

Conclusion

The combination of geotextiles and active materials states an additional solution for all kinds of environmental engineering projects. The contaminant binding feature of the spectrum of active materials ranging from activated carbon and zeolites to different polymers combined with the mechanical and chemical stability of geotextiles ensures an even broad field of application.