2015-Contaminated Site Management in Europe: Sustainable Remediation and Management of Soil, Sediment and Groundwater

(CSME-2015)

ABSTRACTS

Brussels Marriott Hotel, Belgium

October 19-21, 2015

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Session 1: Sustainability Driven Approaches for Decontamination – I

The Regulatory Basis for Sustainable Remediation in the European Union and United Kingdom

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This presentation discusses the findings of a research project to identify pertinent sections of documentation issued both by the European Union (EU) and UK legislative bodies that require, promote or support the application of sustainable remediation principles: the balanced consideration of environmental, social and economic factors in soil and groundwater risk assessment and risk management decisions.

These principles lie at the heart of EU policies, as set out in both the Treaty on the Functioning of the European Union 2012, and also in the Treaty on European Union 1993 (Maastricht Treaty). EU directives are binding on member states and within the preambles to both the Water Framework Directive 2000, and the Priority Substances Directive 2013 are explicit requirements involving consideration of sustainability. The former refers to the need to take account of economic and social development and the potential benefits and costs of action or lack of action in relation to environmental policy, whilst the latter provides further direction on the need to deal with pollutants in the most economically and environmentally effective manner. It also highlights the importance of a cost-effective and proportionate policy for the prevention and control of chemical pollution of surface waters, developed through recognition of scientific, environmental and socio-economic factors.

Both these are overarching statements that are potentially applicable to the overall project objective and entire life cycle and there are similar examples in UK-based legislation. However both EU directives and UK legislation also contain numerous references to sustainability that are relevant to specific scenarios that may come about at various stages within the project life cycle, and in particular, the following:

- Having a site determined as "contaminated land" by a local or regulatory authority
- Receiving an enforcement notice from an authority requiring remedial action.
- Seeking Planning Permission/Discharging Planning Conditions
- Identifying Sustainability as a Key Project Objective
- Determining, Applying, and Modifying Compliance and Assessment points
- Deriving Remedial Target Concentrations
- Evaluating Risk
- Conducting a Remedial Options Appraisal
- Incorporating Cost-Benefit Assessment in Remedial Options Appraisal
- Considering Sustainable Alternatives When Remedial Objectives Cannot be Met
- Engaging with Stakeholders
- Implementing Sustainable Remedial and Waste Management Practices
- Deviating from the Waste Hierarchy Where Justified on Sustainability Grounds
- Implementing a Monitoring and Verification Program

Examples of these will be presented. In all such instances however, the arguments supporting sustainability have to be scientifically robust, transparent to stakeholders and evidenced-based.

Reference:

CL:AIRE & NICOLE, 2015. A review of the legal and regulatory basis for sustainable remediation in the European Union and the United Kingdom. Joint SuRF-UK/NICOLE report. CL:AIRE, London. Prepared by AECOM.

Traceability: A Tool for the Valorization of Excavated Soils in the Flemish Region

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Since the decree on soil pollution and site management was introduced in 1995, Flemish contractors and end-users (receivers of excavated soil) were confronted with new legal uncertainties and concerns regarding the transfer of polluted soil between sites. This made it more difficult to find a destination/use for the excess of soil. Public services in particular refused to accept excavated soil in their building & infrastructure projects, as they were afraid of contaminating their property.

In 2004, a new regulation offered a framework for the use of excavated soil. The basic principles of the new decree were (1) the characterization (analysis) of the soil, (2) a traceability system allowing the follow-up of the transport and (3) the definition of responsibilities. Grondbank has contributed intensely to the development of a usable traceability procedure. A transparent and secured chain was created in order to restore the confidence of end-users of excavated soil.

10 years later, the result is very positive. The re-use of excavated soil has doubled and has become an important alternative for primary materials (sand, clay,...). Confidence in recycled soil has been restored thanks to the certification procedure. The re-use of excavated soil has also been integrated in public tenders. And last but not least, Grondbank developed an insurance policy which is adapted to the specific risks created by the re-use of excavated soil.

Remediation in China

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Soil and groundwater contamination is becoming one of the environmental issues with arising public attention in China. Along with the tremendous urbanization process, large scale movement of industry leads to a significant amount of brownfield, with both potential in environmental risk and good value of property development.

A serial of environmental accident in 2004 and 2006 was considered as the start of public awareness arising on soil contamination in China and has made Chinese government realize the necessity of contaminated site handling; initiatives such as drafting legislation, inventory of potential contaminated sites and demonstrating investigation / remediation have been performed to a certain extent. Meanwhile, two vital international events – Olympic Games in Beijing (2008) and the World Exhibition in Shanghai (2010) have also triggered a great effort in contaminated site management during their years' preparation phase.

Temporary guidelines for site investigation, monitoring and risk assessment have been published in 2014, soon comes guidelines for remediation activities. In the public administration system, Chinese National Environmental Protection Ministry has been responsible for drafting the legislation and national guidelines, while it is the provincial Environmental Protection Department being responsible for guidelines implementation and localization, project monitoring and implementation with practical support from municipal Environmental Protection Bureau.

Although there are still challenges, more and more enterprises are still attracted by the tempting market in China. The statistics shows that in 2011, the number of newly-registrated companies with soil remediation as its main business was over 20, in 2012 this number became over 80. In 2013 this number became over 150 companies. However, it is also indicated that a major portion of these companies are small-medium scale. The market demands for competent and experienced enterprises are still strong.

Although "polluter pay" is still the general principal, most of the projects are financed by public financing. The clear needs for a more practical business model, a more experienced and professional administration as well as methods for both investigation and remediation are identified and confirmed. As the land is a state-owned property in China, the administration of land becomes one of the key responsibilities of the government. This responsibility is spread over a large and complicated administrative system from central government to local municipalities.

Challenges within legislation set-up, administration, technical practice and finance have occurred in Chinese market. It is obtained that, the pilot market in contaminated site management start from those left from the re-location of old industries. Those sites are planned to be developed as new city area due to its potential real-estate value, hence there's an economic interest to cover the remediation cost. Lessons learned from the conducted cases have drawn an overall picture of the existing challenges and opportunities. This will be outlined in the presentation.

A pilot project which involves Danish expertise has taken place in Jiangsu province Wuxi city. Jiangsu is one of the most economically and technically advanced province in China. while Wuxi's Real GDP per capital takes the first place. Phase I investigation has been done in order to find initial facts about the site profile and contamination. Based on the historical review, a wide range of potential contaminates are suspected and therefore scanned. Comparing with the mature practice in Denmark, the differences in decision making progress, soil criteria and relevant legislation are recognized. The joint field work also proved a lack of advanced and efficient methods for both drilling and sampling. As the investigated upper layer of the site is profiled as mainly clay with shallow groundwater level, two source areas with relatively heavy contamination are identified. An intrusive investigation is therefore next step.

Phase II investigation activities including more detailed sampling and analysis, risk assessment and screening of remediation methods is about to be carried out in 2015. Based on the experience from phase I, a more dynamic approach with a combination of several drilling / sampling methods is proposed for investigation. It is also important to perform the correct utilization of conceptual model, and a practical risk assessment. An expert panel is will be established in order to have a smooth and systematic dialogue with both the political administration and the leading experts from Chinese academy and institution. It is expected that this dialogue will find the balance between Danish experience and Chinese requirement in legislation, so as to develop a more practical model for contaminated site management in general.

Comparing with the mature practice in Denmark, some similarities in overall project process are recognized: the entire process is divided in three phases namely "preliminary investigation", "detailed investigation and risk assessment", and "remediation". The decision making process and practice described in these four draft guidelines (chapter 4) are considerably close to the Danish concept, while some differences in detail are obtained during the practice. One of the major differences between Chinese and Danish approach is the requirement for knowledge regarding the conceptual site model. The importance of knowing the sub-surface is not valued enough yet; instead, most of the questions from the authorities and the project owner focus on the contamination concentration and depth. This also lead to a challenge when the consultant propose a systematic approach with a comprehensive conceptual model and risk assessment, as the Chinese side always jump to the question for remediation methods and corresponding costs. Another challenge comes from the different level of knowledge and experience. As the Chinese team have not experienced a mega site like this, it is difficult to explain the benefits of applying some advanced concept e.g. dynamic approach, etc.

The pilot project is still ongoing hence it is too early to conclude the outcome. Despite the challenges, the willingness of cooperation from all stakeholders is solid, and positive progress is constantly obtained. As the result for the first phase, Danish practice has been well-accepted by both the local authority and the project owner. This proved that with the right attitude and set-up, it is possible to export and implement advanced knowhow to such an immature market as China. It is expected from both sides, that this is just a beginning for a mutually beneficial collaboration where a bridge between a knowledge pool and a great market potential could be well established.

Development of Early-warning Lights Classification Management System for Industrial Parks in Taiwan

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The industrial behavior often leads to soil and groundwater pollution, and thus Environmental Protection Administration of R.O.C. (Taiwan EPA) has promoted the action program of soil and groundwater quality management for the industrial parks since 2011. The main tasks of this program were to formulate and promote the lights classification system of early warning and management of soil and groundwater pollution in industrial parks and to set up an online system of quality management. The monitoring resources among the government agencies was coordinated and allocated through consultation. This project also had set up a priority list for high potential polluted industrial parks and investigated their soil and groundwater qualities, and then the administrative control and transition of early warning lights were suggested based on the results. Furthermore, this project drafted the related laws and regulations, executive strategies and plans of soil and groundwater quality management for industrial parks.

In order to get a comprehensive understanding and control of nationwide industrial parks and industrial land, Taiwan EPA didn't only to collect and analyze the operating history, environmental background and monitoring information of 143 designated industrial parks, but also to broaden the region including 338 non-designated industrial parks (such as industrial parks in the urban planning area and D-class construction land).

All of the 143 industrial parks in Taiwan were classified into four early-warning lights, including red, orange, yellow and green, for carrying out respective pollution management according to the monitoring data of soil and groundwater quality, regulatory compliance, and regulatory listing of control site or remediation site. The measures of administrative control and risk management were also taken into consideration to determine the transition of early warning lights, which enhanced the active action of the government agencies. Moreover, an oversight and evaluation system was integrated to provide incentive so as to encourage the local environmental protection authorities. It has shown that the quantity of green-light industrial park with good monitoring and management increased significantly over the past 4 years. In the meantime, pollution investigation and improvement were still needed for the red/orange-light industrial parks to accomplish the purpose of adjusting down the classified lights. The work and goal of soil and groundwater quality management for industrial parks will be carried out on the basis of the inter-agency collaboration by means of the classified lights system of early warning and management as well as the announcement of the status of each industrial park on a regular time schedule.

Keywords: Industrial park, soil and groundwater quality management, early-warning lights classification

Session 2: Remediation via Physical and Thermal Techniques-I

Petroleum Hydrocarbon Mass Removal using Reagent Based Enhanced Desorption Combined with Physical Recovery Techniques

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Keywords: Integrated treatment – enhanced mass-recovery – practical research application – enhanced dual-phase extraction – asymptotic treatment – remediation system closure – European case studies

Objectives: Presentation of technical details, usage scenarios and real-world application experience of a reagent specifically developed to overcome performance limitations and increase the cost-effectiveness of some of the most widely used groundwater treatment approaches in Europe.

Innovative Nature: The presentation presents the science, rationale and principles underpinning the development and application of a new treatment reagent for addressing the widespread challenge of diminishing efficiency of P&T / DPE groundwater treatment systems, supported by case-study examples from full-scale projects across Europe.

Abstract: Dual-phase extraction (DPE) or pump-and-treat (P&T) systems are widely used for the remediation of high concentrations of hydrocarbon nonaqueous phase liquid (NAPL) at contaminated sites. While the initial phase of DPE system operation typically achieves rapid reduction of NAPL the long-term effectiveness diminishes and the system often reaches an asymptote. Further operation of a system in asymptote conditions would provide little incremental benefit in treating soil or groundwater contamination thus negatively impacting both project costs and time.

The leveling off of DPE effectiveness typically arises as a result of hydrocarbon distribution through zones of differential matrix permeability, the presence of slowly dissolving smeared or sorbed hydrocarbon contamination, or a combination of both of these factors. For many remediation practitioners the next logical choice for remediation when DPE operation is asymptotic is to use In Situ Chemical Oxidation (ISCO). While the use of ISCO can be successful in many instances there are still two main limitations to ISCO to treat heavy sorbed phase contamination. The first being that DPE systems are often used in low permeability sites where they achieve greater treatment radii because of the beneficial use of high vacuum flow. These very same soils may prevent efficient distribution and contact of a chemical oxidant. The second point is that while a DPE system may have reached an asymptote the corresponding soil and groundwater concentrations may still be quite high meaning that the number of injections and volume of reagent required would be costly.

The use of surfactants to enhance recovery of sorbed-phase or smeared hydrocarbon is another option, but applications are rare owing to problems of cost, pore-blockage, trapping of residual hydrocarbons by sub-CMC residual surfactant, and high residual surfactant biological oxygen demand (BOD) that inhibit follow-on biodegradation or natural / enhanced attenuation of residual hydrocarbon.

This presentation will provide information on a reagent-based approach which systematically addresses the above issues in order to increase the efficiency and expedite the closure of physical extraction-based clean-up projects (DPE, pump-and-treat, etc.). This technology is entirely inorganic and presents no BOD yet provides combined ISCO and enhanced desorption at contaminated sites to treat bound hydrocarbon and NAPL. This approach can also be used to increase efficiency at failing DPE installations for fast and cost-effective mass reduction. An overview of the results from laboratory and field studies will be presented and the potential modes of usage and anticipated benefits to common remediation projects explored.

Successful Application of Air Sparge / Soil Vapor Extraction Remediation in a Drinking Water Aquifer at a Shopping Center, California, United States of America

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Historical operations of a dry cleaner (1965 through 2003) and practices of disposing of spent Tetrachloroethylene (PCE) into the sanitary sewer resulted in subsurface impacts to soil gas (vadose zone) from the ground surface down to the groundwater (~135 feet / ~41 meters below the ground surface). Investigation activities identified several high permeable layers from the ground surface to the groundwater and identified that the majority of the PCE in soil gas existed in the higher permeability layers. PCE entered the environment through leaks in the sanitary sewer and aerial distribution of PCE in soil gas included beneath parking lot areas (both in front and behind the shopping center buildings) as well as beneath the existing shopping center structures. In addition, concurrent with the subsurface soil gas investigation, groundwater investigation activities resulted in identifying the lateral and vertical extent of PCE in groundwater. PCE detected in groundwater was restricted to the upper 10 to 15 feet (3 to 4.5 meters) of the first encountered water-bearing zone / aquifer, however, concentrations of PCE in excess of the primary drinking water standard in the United States (the United States Environmental Protection Agency [USEPA] Maximum Contaminant Level [MCL] of 5 micrograms per liter [µg/L]) existed approximately 1,000 feet (305 meters) downgradient of the estimated release point. Dense Non-Aqueous Phase Liquid (DNAPL) was not detected at this site.

PCE concentrations in both soil gas and groundwater required remedial action. Initial PCE soil gas concentrations were detected as high as 800,000 micrograms per cubic meter (µg/m^3). PCE in groundwater was detected as high as 300 µg/L. A one day pilot test was conducted in the subsurface to evaluate the relative permeability of the subsurface to soil vapor extraction. Soil vapor extraction was deemed suitable for a remedial approach for soil gas. Given the nature of the aquifer (potable municipal drinking water source), in-situ technologies such as enhanced reductive dechlorination or oxidative approaches were deemed infeasible due to potential unwanted byproduct production. Air sparge was evaluated in a feasibility study and a 90 day pilot text of the soil vapor extraction and air sparge technology was conducted. Extremely successful response in the subsurface from the 90 day pilot test resulted in the full scale operation of the air sparge and soil vapor extraction systems. The soil vapor extraction system was designed and successfully implemented to "reach" beneath the shopping center buildings to remove PCE without destroying or altering existing shopping center buildings or disrupting the shopping center operations. Water quality objectives and indoor air / vapor intrusion soil gas goals were met in less than 2 years of full time system operation.

The Central Valley Regional Water Quality Control Board recently concurred with proceeding with a no further action (NFA) determination for this site.

From Red Hot To Shivering Cold
In-Situ Soil Remediation with Electrical Resistance Heating and Vapors Treatment by Cooling

Marco van den Brand
HMVT, The Netherlands

HMVT is a specialist in both in-situ soil remediation as well as mobile Industrial vapor treatment. During the conference we will present the results of a thermal in-situ remediation project we carry out in Anderlecht using Electrical Resistance Heating (ERH) and where we treat the steaming vapors by cooling them towards -20°C. This vapor condensation technology we also often use during our mobile vapor treatment projects in the petrochemical Industry.

Red hot
On an in-situ soil remediation project near Brussels we undertake a thermal in-situ remediation project, heating the subsurface by Electrical Resistance Heating (ERH). Using electricity we heat the groundwater towards ca. 100°C. By doing so, volatile chlorinated solvents almost completely vaporize from the subsurface. The technology is very robust and quick to remove even dnapl's.

Shivering cold
The (boiling) vapors are captured by an SVE system and treated on site. We treat these vapors by a condensation unit we developed ourselves. In an inherent (ATEX) save way we condensate the extracted vapors to the liquid phase. This is achieved by cooling the vapors to a temperature level of ca. -20°C. Any residual vapors are treated by scrubbing with an aliphatic liquid, followed by a catalytic oxidizing unit.

This mobile condensation- and scrubbing technology is initially developed to treat vapors that occur during industrial cleaning and maintenance projects. During such projects we offer tailor-made mobile vapor treatment solutions. The nice aspect of condensation is that it can be used in situations where very high vapor concentrations are expected and no explosion risks are allowed and incineration is no option.

Project presentation
At the Anderlecht site we combine ERH with the vapor condensation technique. At this site there is a complex mixture of vapors to be treated, also in very high influent concentration levels. During the presentation we focus on both the ERH as well as the vapor condensation techniques and results in detail.

Enhanced Oil Recovery (EOR) with Thermal Conductive Heating (TCH) and Solvent Soil Flushing at the Former Low Temperature Carbonization Plant Deuben, Saxony-Anhalt, Germany

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At the former low temperature carbonization plant „Schwelerei Deuben", massive soil and groundwater contaminations are caused by residual and free oil phase (LNAPL) which have a lasting adverse effect on the groundwater especially with phenols, BTEX, PAH and ammonium. The LNAPL reached the site boundary as mobile local floating and incoherent blobs. The contaminant plume in the groundwater has exceeded the boundary significantly. A conventional pump & treat system with a hydraulic supported oil skimming effectively prevents the further propagation of the groundwater contamination.

The mid-term remediation strategy is to achieve a stationary groundwater plume without further contaminant migration applying enhanced natural attenuation. To reach this goal stepwise, innovative remediation technologies for enhanced oil recovery (EOR) have been tested to optimize the site remediation strategy and to enable site specific permissions for the technology application by the authorities.

Two pilot tests for the EOR-remediation are implemented by the in-situ technologies mobilizing solvent soil flushing (solvent: 100% n-butanol) in sandy layers and in-situ thermal treatment with thermal wells (THERIS method) in silty, loamy formations. Both methods complement regarding the hydrogeological boundary conditions. Required values have been achieved during the pilot field tests demonstrating the efficiency of the applied EOR methods. Design and conduction of both methods have been confirmed technically and legally within an acceptable time and cost expenditure:

- significant reduction of residual oil phase and its harmful effect (contaminant emissions) from the unsaturated zone,
- recovery or immobilization of mobile oil phase from the unsaturated and the saturated zone,
- stimulation of an efficient aerobic in-situ degradation of the remaining contaminant mass flux in the groundwater as a permanent ENA-process.

Process-related objective of mobilizing solvent soil flushing is to convert moderate mobile oil-phase into a swelling oily mobile phase by infiltration and spreading of n-butanol as a solvent fluid at the capillary fringe zone increasing this way the relative permeability. The mobile phase is recovered at wells as much as possible (preliminary remediation). In a second step, the resting ratio of butanol in the residual oily phase and in the groundwater has to be reducted by intensive water flushing. Finally, aerobic in-situ degradation of dissolved butanol and dissolved contaminants has to be stimulated by the injection of oxygen gas.

Process-related objective of the thermally EOR-THERIS is the mobilization of residual oil phase by reducing viscosity and surface tension due to increased subsurface temperatures.

Mobile oil phase was recovered by a multi-phase fluid pump and skimming, soil vapour extraction avoided an uncontrolled migration of volatile compounds like BTEX. Significant thermally enhanced oil phase mobilization could be observed by reaching temperatures at and above approximately 70°C in large areas of the pilot test.

Since 2013, both EOR techniques have been proved in pilot test areas of approximate 100 m², embedded into the continued pump & treat system.

The pilot tests at the former low temperature carbonization plant Deuben take place by order of the Lausitzer und Mitteldeutsche Bergbauverwaltungsgesellschaft mbH.

An Integrated Multiphase Extraction, Soil Vapor Extraction, and Air Sparging Approach for Treatment of LNAPL Impacts

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An integrated remedial approach was developed to address two areas of concern (AOC) with light non-aqueous phase liquid (LNAPL) impacts within the footprint of a demolished building. One AOC presented free-product No. 4 fuel-oil impacts, the other, free-product gasoline impacts. As a result, the soil and groundwater at the site were impacted with volatile organic compounds (VOC), primarily benzene, ethylbenzene and toluene; semi-volatile organic compounds, primarily naphthalene, phenanthrene, and pyrene; and metals, primarily lead and zinc. The site is a New York State Brownfield Cleanup program site in Brooklyn, New York. Redevelopment of the site with a 12-story residential apartment building began in November 2014.

Because of the extent and nature of the contamination, new building, site access restrictions, and nearby receptor concerns associated with the urban location of the site, an integrated remedial strategy required carefully formulating a remediation technology, health and safety precautions, and design remedy (i.e., placement of treatment wells and process equipment). The remedial approach consists of a multiphase extraction (MPE) system, a soil vapor-extraction (SVE) system, and an air-sparge system to simultaneously address the fuel oil and gasoline impacts. The objective of the MPE system is to remove the fuel oil and meet groundwater remedial goals. The goal of the SVE and air-sparge systems is to remove VOCs from the gasoline-impacted unsaturated soils, remove gasoline, and meet groundwater remedial goals. In addition, an active vapor-mitigation system was designed to mitigate any vapor intrusion resulting from free-product, soil, and groundwater impacts beneath the slab of the new apartment building.

The MPE system design consists of a network of ten extraction wells, a liquid ring-pump skid with an airflow rate capacity of 150 standard cubic feet per minute (scfm) at 25 inches of mercury (inHg) vacuum, an air-moisture separator (AMS), an oil-water separator (OWS), two holding tanks for the extracted groundwater storage, and carbon adsorption vessels for off-gas treatment. The design of the SVE system (seven wells) and air-sparge system (four wells) includes an explosion-proof-rated positive-displacement blower skid with an airflow rate capacity of 250 scfm at 15 inHg vacuum, an air compressor with an airflow-rate capacity of 100 scfm at 15 pounds per square inch (psi) pressure, an AMS, and carbon adsorption vessels for off-gas treatment. All SVE process equipment, including control panels, is designed to be explosion proof, meeting the requirements of National Electrical Code (NEC) Class I, Division 1 Standards. Because of the planned residential use of the new building, all treatment wells, manifold, and instrumentation associated with the remediation and vapor-mitigation systems are installed below the finished grade of the building structural slab. The remedial strategy, full engineering design, and implementation data of the systems are presented in this case study.

Pilot on Thermal Enhanced SVE of Mercury in Soil and Bedrock under an Ongoing Chloro-Alkali Plant

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Background/Objectives. Because of a decision from the Swedish government, the mercury based Chlor-Alkali plant at INOVYN Sverige in Stenungsund, Sweden, must be closed down by December 2017 and the mercury contamination need to be remediated. The plant started in 1969 and investigations show almost no contamination outside the plant, but that up to 1.5 ton of primarily elemental Hg could be present directly under the plant in thin sand fill and shallow fractured crystalline bedrock. A demolition of the plant and excavation of the thin fill layer is estimated to only remediate a minor part of this Hg mass. Potential remediation techniques have been evaluated and it was determined that soil/bedrock low temperature heating coupled with vacuum extraction (SVE) is the preferential, sustainable remediation technique for the site.

Approach/Activities. INOVYN and Golder Associates in collaboration have designed an indirect heating technique using steel casing inserted in the sand and bedrock vadose zone, which are heated using steam (at a temperature of about 140°C), delivered from the plant, to promote heat transfer into the soil/bedrock matrix through conduction. Three heating elements have been installed in a triangular pattern. Two central air extraction wells, one each for soil and bedrock, have been installed in the middle of the heating zone to extract mercury vapor. The treatment cell is equipped with multi-level monitoring wells. An air sampling technique has been elaborated by INOVYN to collect mercury from the humid and hot soil gas. A complete mass balance was performed on soil, bedrock, water and gas. Speciation of the mercury forms was performed on samples collected from water, soil and bedrock.

The pilot was conducted inside the plant, during ongoing production, and has been in operation for four months and is planned to operate for up to 6-months.

Results/Lessons Learned. The heating rapidly increased the mercury extraction rate, the extracted concentration of mercury going from 2 500 to 28 000 µg/Nm^3. Even at low temperature, it was found that not only elemental mercury was extracted. Other forms of mercury, much less volatile, were extracted as well. After four months around 10 % of the expected total mercury mass in the pilot cell has been extracted.

The temperature also rose rapidly in the monitoring wells, especially during the first month. After four months the temperature was around 50-55°C in the top two meters below the plant approximately one meter from a heating well. The temperature increase in the saturated zone, led to approximately one order of magnitude higher mercury concentrations in the water as it increased the solubility. However, no increased spreading outside the pilot cell was seen.

The drilling for installation, inside the plant, showed that a free water table was encountered only 1 meter below ground level, most likely consisting of perched rain water from uphill areas. Gas could not be extracted from the bedrock below 1 meter deep and dewatering techniques is under investigation in order to improve and assess Hg-extraction from the bedrock fractures.

Session 3: In-Situ Bioremediation-I

Microbial Surfactants for Soil Remediation Processes

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To enhance the bioavailability of persistent pollutants, and accordingly the efficiency of their biodegradation, the use of natural surface active additives seems to be crucial for many targeted bioremediations. In this context, the bacterial rhamnolipids, offering a variety of congeners, no / low toxicity for water / soil mikroflora as well as stability towards the extremes of environment, logically attract attention. In this connection, different bacterial strains were used to select a multicompnent (rhamnolipid) producer (s) in the background of the effect of different physiological factors affecting reproducibly the yield and pattern of growth-associated production of stable mixture of these glycolipids. In the case of selected producers, this study deals with optimization of production, purification, and composition of respective rhamnolipid mixtures. Moreover, their unwanted biological activity in bacterial and yeast populations was investigated and the single strain and co-cultures cultivations were proposed as a possible way to produce rhamnolipidů mixtures with a specific composition and different physiochemical properties. An additive goal of this work was to scale up the ramnolipid production. In addition, the enhancement of the efficiency of model hydrophobic substrates biodegradation was verified for selected rhamnolipidů mixtures.

Practical Issues and Lessons Learned Regarding the Installation and Operation of a HGB Cell

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At a site in Tessenderlo, Belgium, a groundwater contamination with chlorinated aliphatic hydrocarbons (CAH) is present. These compounds (1,2-dichloroethane and chloroethenes) are very difficult to remediate because of their physical and chemical characteristics. In most cases, traditional remediation techniques are often inadequate, time-consuming and expensive.

Several years of research by the project team (University of Ghent, Avecom and RSK) resulted in an innovative in situ bioremediation technique that is currently demonstrated on full scale (European LIFE+ project with ref. LIFE08 ENV/B/000046 LVM-Biocells).

The step from research installation to full scale implementation turned out to be a challenging one. During the project different field tests were performed to optimize the implementation: injection of nutrolase versus lactate, tests on low cost injection equipment, development of filters, pumping tests, bag filter tests.

This presentation will give an overview of the design and operation of a hydrogeobio (HGB) cell for biostimulation and will also show some results of the tests that were performed.

The performance of the HGB cell towards degradation of the CAH was successful. Our results show that bioremediation of the CAH impacted groundwater was complete within the HGB cell. However, up to now, the HGB cell has only run continuously for a maximum of 6 months due to the different bottlenecks that were encountered.

Lessons learned from this project will be shared.

Surfactant Enhanced Push-Pull Method for In-Situ Remediation of Petroleum Contaminated Soil and Groundwater

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This study evaluates a novel in-situ 'Push-Pull' method for surfactant enhanced remediation of petroleum hydrocarbon contaminated soil and groundwater at the Chester River Hospital Center (CRHC), Chestertown, Maryland. This site has been contaminated for over 20 years as a result of an on-site diesel spill from an underground storage tank.

The historical application of a conventional pump and treatment remediation approach at the site slowly recovered greater than 80% of the original spill mass over a 19 year period. However, the residual contamination currently presents a significant risk of impacting the nearby Chestertown municipal groundwater aquifer. Local stakeholder, legal and regulatory pressure required the site owner to evaluate innovative and cost-effective methods to enhance and expedite the site remediation to mitigate this risk in a sustainable manner.

A pilot-scale application was completed in 2014 at four (4) impacted wells near the source zone using the 'push-pull' surfactant enhanced remediation process to target the contaminant smear zone within a silty medium to fine sand layer. A total of three (3) 'push-pull' events were completed over a two week period, with on-going groundwater quality monitoring, and real-time field test measurements associated with each event, to evaluate the efficacy of this novel method for full-scale remediation.

The pilot-scale test results indicated that the in-situ 'push-pull' surfactant enhanced remediation method was very effective for the dissolution and recovery of sorbed petroleum hydrocarbon contaminant mass in the saturated and unsaturated smear zone. The calculated increase in contaminant mass recovery rates ranged between one thousand percent (1,000%) to over eighteen thousand percent (18,000%) compared to baseline levels at the subject wells associated with the existing pump and treatment remediation system.

The success of this pilot-scale 'push-pull' method received Maryland Department of the Environment (MDE) regulatory approval for full scale application in 2015.

Modeling of a Biostimulation Cell for the Remediation of a Site Situated on a Groundwater Divide

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Contamination sites located on or close to a groundwater divide have a limited natural groundwater flow. This low groundwater flow hampers the remediation of such sites. To enhance the groundwater flow a hydrogeobio-cell (HGB-cell) was designed consisting of a number of injection and extraction wells. The design of this cell was made using a numerical model which simulated the activity of dechlorinating bacteria (DCBs), iron and sulfate reducing bacteria (IRBs and SRBs) along with the activity of methanogenic micro-organisms (MGMs). The activities of the aforementioned bacteria and micro-organisms were directly linked with the fermenting bacteria. The activities (metabolisms) of all these bacteria and micro-organisms were modeled using the double or single Monod equation. With this model the evolution of the 3D distribution of the contaminant 1,2DCA was simulated along with the cations (H^+, Na^+, K^+, Mg^{++}, Ca^{++} and Fe^{++}) and the anions (Cl^-, $SO4^{--}$ and $Lactate^-$). The pH-dependent CO_2-water system was simulated using two parameters: $(CO_2)_T$ and pH. Furthermore, the evolution of the 3D distribution of methane which is the result of the activity of the MGMs, was simulated. The possible precipitation of the minerals FeS, $FeCO_3$, $MgCO_3$ and $CaCO_3$ was also considered. In the framework of the European Life+ project LVM-Biocells (ref. LIFE08 ENV/B/000046) the HGB-pilot test was performed and extensively monitored. These data were compared with the model results.

A significant amount of parameters was involved in the algorithm. The hydraulic parameters were determined by a pumping test in the field before the start the operation of the HGB pilot test. The parameters controlling the activity of the bacteria and the micro-organisms were obtained from literature or were derived by calibration of the model with chemical data collected during the HGB-pilot test. The growth of the bacteria (DCBs, IRBs and SRBs), the micro-organisms (MGMs) and the mineral precipitation can result in a reduction of the pore space. This porosity reduction can subsequently cause a reduction of the hydraulic conductivity. With the numerical model this reduction of the hydraulic conductivity was simulated. The parameters involved in this process were also estimated based on the reduction of the hydraulic conductivity during the HGB-pilot test. The reduction in hydraulic conductivity was obtained by the comparison of the results of a step drawdown test at the end of the HGB-test with the results of the pumping test before the start of the HGB-pilot test.

Session 4: Site Characterization and Remediation-I

Why High-Resolution Data Sets are Necessary to Assess the Age, Location, and Vapor Intrusion Potential of VOC Sources beneath Buildings

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Chlorinated VOC sources are commonly located under commercial/industrial buildings resulting from "back door" releases that typically pre-date the establishment of strict environmental regulations. Many times, these back door areas lie beneath the current, expanded footprint of the facility. Finding someone having firsthand knowledge of the pre-regulatory disposal practices and areas is becoming harder as the population ages. Because of this, high-resolution data sets have become a necessity in assessing the age, location and vapor intrusion potential of VOC sources beneath buildings.

High resolution does not necessarily equate to high cost. Recent advances in soil gas sampling and evaluation techniques can be used to build high-resolution data sets in a practical, expedient, and marginally intrusive manner even at operating facilities. The resultant data set, combined with GIS analysis, greatly improve remediation efforts and successful project outcomes.

To demonstrate the effective use of a high-resolution data set, a case study of the approach will be presented. The subject facility manufactures and assembles aerospace components within a 6,000 square meter facility that houses areas for machining, degreasing, plating, painting, assembling, and testing. Investigative activities were required in all of these areas, but could only be completed after normal business hours, and could not interfere with daily operations. To meet these requirements, our team developed a sub-slab sampling point that allowed a two-man crew to collect approximately 160 sub-slab soil gas samples for analysis in less than a week of field time. Samples from all of these points were collected into 22-ml evacuated glass vials for analysis via gas chromatography. A GIS-database application was developed to house the field and analytical results as well as georeferenced aerial photography and fire insurance maps.

The investigation revealed that tetrachloroethene and tricholorethene were released in approximately 1950 near a loading dock and along what was the back outer edge of the facility. These sources, which had migrated to a depth of 5 meters, were discernible by the sub-slab soil gas data set and were further delineated through targeted geoprobing. The sources were remediated using injections of emulsified zero-valent iron (EZVI).

High Resolution Groundwater Flow Diagnostic System for Optimization of In-Situ Site Remediation and Environmental Protection

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The success of in-situ remediation strongly depends on the level of knowledge and a quality description of the geological structure of the contaminated site. Most failed applications of in-situ remediation technologies were based on successful laboratory and field pilot tests. The failure of the remediation methods is usually not a failure of the technology itself, but it is a failure of the insufficient description of the geological and hydrogeological conditions at the site. The basic conditions for successful remediation include a detailed description of contaminant distribution, proper understanding of the groundwater flow, a detailed geological description, a description of stratification and fracturation, a description of aquifer inhomogeneities, and an understanding of the directions and velocities of groundwater flow. In recent years, high resolution methods have been used for a very detailed description of the contamination as well as the geological and hydrogeological conditions. A complex of methods related to well-logging technology is a very effective system for high resolution diagnosis.

Some data obtained from well-logging cannot be obtained by other methods. Well-logging is irreplaceable from this perspective. One such group of data is used to clarify the groundwater flow in the borehole and clarify its relation with the geological and tectonic structure and the construction of the well. Using an appropriate set of well-logging methods we can determine depths of permeable layers and of open fractures in which there is a flow, it is also possible to measure the intensity of flow. The measurement can determine whether there is a flow across the borehole or whether there is water "short circuit" between two permeable layers. Well-logging can also be used to determine the groundwater flow direction. The advantage of well-logging is its ability to detect fast but also very slow flow: centimeters per day, and slower. If there is a group of wells at a location, it is possible to measure this group of wells to draw conclusions about groundwater flow not only in the wells themselves but also in the whole rock body. This method is widely applied to sites with contaminated groundwater. Based on the results it is possible not only to describe the current state of migration of the contaminated water (in favorable cases it is possible to also record the form of pollution i.e. water insoluble) but a fairly accurate estimate can be made of the further spread of the contamination plume. Well-logging thus provides important information that can be used in planning the optimal remedial method as well as during the actual remediation: in the risk analysis stage, during the remedial work and also in the course of monitoring after completion of the remediation.

This paper describes examples of measured data from sites and demonstrates the significance of well-logging measurements for a detailed understanding, enhancement and optimization of in-situ remedial systems. Detailed measurement and interpretation of natural conditions together with a detailed description of the contaminant distribution provide essential information for the design and dimensioning of the in-situ application of reactive agents and monitoring of in-situ remedial technologies. The presented data are from the interstitial soil environment as well as from a fractured bedrock site.

Acknowledgements: We would like to thank the TA ČR for their financial support (project No. TA03020290, research centre "REGENERACE")

Improved Geostatistical Estimation of Hydrocarbon Pollution in Urban Soils

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Hydrocarbon soil concentrations usually present some very large values, which make the geostatistical study difficult. Indeed, variograms become then erratic, and the spatial structure is poorly identified. Moreover, when data are irregularly located, circular or elliptic hot spot can appear around the large concentration data, making the estimation not very realistic.

Rivoirard, Demange, et al. (2012) developed a new model in the mining context for heavy-tailed grade distributions. This "top-cut" model justifies the industrial practice consisting in cutting the highest concentrations to a fixed value, while providing objective criteria for this "top-cut" value and avoiding bias in the estimation.

The spatial structure of the concentration is described by the joint behavior of intermediate and low concentrations and the geometry of largest values. Concentration hot spots are supposed to be erratic within the large value area, but not everywhere on the site. The estimation thus obtained appears to be much more realistic. The map showing "polluted", "non polluted" and "uncertain" zones can be derived from the estimation.

In conclusion, the "top-cut" model can help to improve the geostatistical estimation of complex soil pollutions.

Feedback on 3D Geochemical Modelling of Urban Soils and Subsoils at Quarter to City Scale in Europe

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Urban geochemistry covers a wide range of a) scales - from sample to city through site to quarter- and b) components of the urban system: soils, subsoils, underground, watershed, sediments, water, air… Within the Cost SubUrban European project (TU1206), the working group on geochemistry focuses on soils and subsoils representation at quarter to city scale. It aims at identifying to which extent the 3D modelling of soils and subsoils geochemistry is used in European cities, how urban managers interact with geoscientists and use such representation, if specific recommendations may be proposed.

The methodology adopted to reach this goal is a survey on practices by Cost SubUrban country partners, completed by a literature survey and discussions with geochemists and urban planners.

The 3D geochemical modelling of urban subsoils seems scarcely carried out at quarter to city scale, compared to 2D approaches that map soil geochemical quality. It appears mostly linked to redevelopment projects including brownfields, where subsoils contamination (e.g. by former industrial or mining activities) may impact the management of excavated materials. Very expansive, such approaches would be driven mainly by economic reasons (interest/feedback sufficient). In comparison, health drivers are frequently cited for 2D mapping of soil geochemistry. The 3D modelling of groundwater quality is not considered here.

Most preconisations for 2D data acquisition and mapping of soil geochemistry may be applied for 3D modelling of subsoils geochemistry. These are very well described in a book edited by the Eurogeosurvey group on urban geochemistry (e.g. sampling strategy, sample preparation, analysis, verification...). The preconisations linked to 3D modelling (e.g. data management, interpolation...) may be used too (there is a working group on this topic within the Cost SubUrban project). Specific preconisations could be proposed in addition (e.g. sampling according to lithology rather than at a systematic depth, data interpretation...).

The 3D representation of subsoils geochemistry may serve as a decision aid tool for urban planners, developers and managers. It may be used for instance to anticipate the volume and quality of excavated materials, to adapt a redevelopment project so as to optimise the management of excavated materials and/or limit health risks. It may complete a preliminary 2D approach, or be directly carried out in zones with suspicions of contamination problems. Its generalisation would allow a better management of subsoils as a natural resource. The capitalisation of existing geochemical data in local and/or national databases would help building a general knowledge.

LNAPL Remediation Using Next Generation In-situ "Trap and Treat®" Technology

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Background/Objectives. The site is located south of Copenhagen, Denmark. After extensive remedial effort and cost (greater than $1 million) free product continues to be observed in 5 monitoring wells. Benzene and other petroleum hydrocarbons in groundwater, in the majority of the on-site monitoring wells within the impacted area, remain at significant concentrations greater than allowable levels. LNAPL is observed in 5 monitoring wells (B113, B106, B105, KB5, and B108) within a 1,000 ft2 area of the site. B113 contained 2 feet of NAPL in February 2011.

Approach/Activities. A Remedial Alternatives Analysis (RAA) was prepared by the primary consultant for the site. In the RAA, Trap & Treat® technology involving injection of BOS 200® was identified as a feasible remediation approach at the site. The owner and primary consultant decided to first conduct an in-situ pilot test at the site to explore the feasibility and applicability of the technology at the site. They chose the area of the site where the greatest amount of LNAPL was present (B113). The pilot area was approximately 1,000 s.f. Prior to installation, a Remedial Design Characterization (RDC) high density sampling event was conducted in the Pilot Area. The high resolution sampling event was used to develop a three dimensional conceptual model of the hydrocarbon mass within the pilot area. The high resolution sampling included: the installation of two well clusters, two continuous soil borings completed with samples collected and analyzed every 2-vertical feet, and four MIP borings. The soil and groundwater results from the RDC were used to calculate the vertical and horizontal distribution of hydrocarbon mass in the pilot test area. The hydrocarbon mass was used to develop the pilot test injection design loadings

Results. A total of 178 injections were installed in 18 injection points using high flow and high pressure. A discussion will be provided on methods and procedures used to overcome short circuiting issues. As much as 5 feet of LNAPL accumulated in one of the new well clusters installed in the center of the pilot area. The well clusters and sentinel wells were monitored for six months. The monitoring confirmed that the LNAPL has been successfully removed. The owner and primary consultant have chosen to move forward with full-scale treatment of the site based on the success of the pilot test. Results from the full-scale treatment will be available in May 2015.

Session 5: In-Situ Chemical Oxidation (ISCO)

PCE Persulfate Oxidation Treatability Study of PCE and Metals Behavior during Oxidation

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Background/Objectives.

Chemical oxidation is becoming a popular remediation technology in Brazil especially at sites contaminated with chlorinated compounds. Short term and terminal solutions in remediation are important characteristics in places where residential redevelopment is required. Regulators are bringing up some questions such as lixiviation of metals in ISCO remediation, and this paper reports results in PCE decrease within a treatability test and also in the field. The site is located in a very populated area downtown São Paulo city, Brazil. It used to be a Stove Factory for about 100 years and it has 240.000 yd^2. The local geology consists of sandy clay and clay sediments of São Paulo Formation.

Approach/Activities.

Treatability study was performed focusing in two different approaches: PCE, TCE and DCE degradation and metals lixiviation. In order to evaluate contaminants degradation, five different conditions were performed, including conditions with different concentrations of surfactant, persulfate (FMC®) and catalysis evaluation. Degradation studies were performed with slurry prepared with soil, groundwater and reagents in a PVC closed reactor. ORP, pH and DO were determined with 1, 2, 4 and 10 days. Metals behavior was evaluated using and open reactor containing soil, groundwater and persulfate (FMC®). Metals concentrations were determined in groundwater before and after oxidation reaction.

Results/Lessons Learned.

Laboratory treatability study showed that persulfate (FMC®) oxidation was efficient in contaminants removal. Two evaluated conditions have achieved final contaminants concentrations lower than legal limits established by São Paulo State laws. The best condition showed 84%, 79% e 90% removal of PCE, TCE and 1,2cis-DCE, respectively. It was observed that surfactant was effective in solubilizing contaminants adsorbed to the soil of this area.

Results related to the metals behavior during oxidation indicate that, from 19 metals evaluated, 11 showed no variation or no significant variation in groundwater concentration (Sb, As, Ba, B, Cd, Co, Pb, Hg, Ni, Ag and Se). From these 11 metals, five showed concentrations below LOQ before and after oxidation (Sb, Pb, Hg, Ag and Se). Al, Cu, Cr, Mo and V exhibited an increase in groundwater concentration, indicating lixiviation from soil. Nevertheless, geochemical analyses and some Pourbaix diagrams showed very small change in pH x Eh relationship, indicating that metals mobilization is unlikely to happen in the field evaluation of ISCO.

Field application was initiated in Mars 2013 and until July 2013 groundwater contamination has decreased around 95% in monitoring wells and residual contamination is related to hotspots/

previous industrial source area. No metals mobilization was observed and only Al and Cu had small increase in concentration (trace level).

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ISCO Technical Developments – Persulphate Catalysis vs. Activation

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Key Words: *In Situ* Chemical Oxidation (ISCO), persulphate / persulfate, PersulfOx™, activation, catalysis, laboratory studies, field studies, groundwater remediation.
Objectives: Technical presentation on the application of catalysis to ISCO technologies, evaluating performance, efficiency, and safely benefits of a new catalyst over traditional activation methods of sodium persulphate.

Innovative nature of proposed topic: sodium persulfate with intrinsic catalyst, advantages presented over traditional activation approaches, laboratory and field performance data, side-by-side catalyst vs. activator comparisons.

Abstract: The use of persulphate (sodium or potassium) as an *in situ* chemical oxidation (ISCO) agent for environmental remediation is now approaching a decade old. Under suitable circumstances and correctly managed, the ISCO technology offers benefits of speed and broad treatment range to the mass-reduction of organic contaminants in the subsurface. To be fully effective as an ISCO agent however, persuphate must be activated to overcome its innate stability – without this, it can remain unreactive the subsurface for long periods of time without benefit to remediation. Traditional persulphate activation methods include addition of chelated metals, heat, hydrogen peroxide and high pH (base). These approaches each have their attendant advantages and drawbacks and have developed little, if at all, over the past ten years.

Recently however, a catalyst for persulphate ISCO has been developed that unlocks persulphate treatment efficacy equal to or exceeding that of traditional activation chemistries but without the attendant activator drawbacks or requirement for high volumes of activator that present health and safety, cost, fieldwork and logistical demands. Since the catalyst is not itself consumed by the reaction, only a small volume is required for full efficacy. This reduces the total volume of reagent to be injected to secure a requisite treatment performance, thereby simplifying and shortening fieldwork duration and reducing project costs. The low catalyst volume also enables the persulphate and catalyst to be commercially provided as an all-in-one product without compromising stoichiomentric efficiency.

This talk offers a succinct description of the new persulphate catalysis, contrasting this with traditional activation approaches for context. Comparative third-party performance data obtained from laboratory testing and from high sample-intensity side-by-side field performance of catalyzed vs. traditionally activated persulphate are presented and discussed. Key performance considerations from technical, commercial, regulatory and operational standpoints are explored and the technology is critically evaluated.

It is anticipated that the technical presentation and case studies will be of interest to site owners, regulators, consultants and remediation professionals alike.

ISCO of TCE Impacted Groundwater in Basalt Bedrock through an Enhanced Fracture Network

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In-situ chemical oxidation (ISCO) using blast fracture trenches and hydraulic fracturing enhancements resulted in a significant decrease of the source of a trichloroethene (TCE) groundwater plume in fractured bedrock at a site in northern New Jersey. The site is an active industrial research and development facility. The remedial objective was to mitigate the dense non-aqueous phase liquid (DNAPL) source zones that were defined as areas with TCE concentrations in groundwater exceeding 10,000 micrograms per liter (µg/L). ISCO was implemented using both potassium permanganate ($KMnO_4$) and sodium permanganate ($NaMnO_4$) after the creation of an extensive enhanced fracture network in the Preakness Basalt bedrock. Three ISCO injection events have been completed at the site to date: primary injections were from 2006 to 2007, a supplemental injection in 2009, and the most recent injection event in 2011. Approximately 94,250 gallons of permanganate solution (40,800 pounds) were injected into the bedrock as part of the ISCO remedy.

This presentation focuses on the most recent oxidant injection consisting of approximately 43,200 gallons of 2.5% concentrated potassium permanganate solution (9,100 pounds) into the source areas and describes techniques that were used to overcome the challenges with regard to oxidant delivery, distribution, and contact in the subsurface. Hydraulic fracturing was performed in select injection wells to extend the existing fractures and facilitate oxidant delivery in the subsurface. Specially designed oxidant distribution manifolds, high pressure wellhead assemblies, and overnight gravity feed injection scheme were used to further facilitate oxidant delivery in the subsurface.

The strategy of aggressively targeting the source areas through the creation of an enhanced fracture network has been effective in eliminating the DNAPL source zones and reducing the TCE groundwater concentrations significantly. Prior to the start of remediation at the site, TCE concentrations in groundwater were observed as high as 410,000 µg/L in monitoring wells (November 2002) and as high as 950,000 µg/L in rock borings (March 1998). The maximum TCE concentration detected at the site in May 2012 was 7,900 µg/L. The remedial measures conducted at the site reduced the average TCE concentration at all site wells by approximately 90%. An additional polishing ISCO injection was performed in October 2014 to target the residual TCE concentrations in groundwater that were exceeding 1,000 µg/L. This source area ISCO and downgradient plume monitored natural attenuation (MNA) approach has obtained regulatory acceptance and a Technical Impracticability (TI) waiver, and proved to be a cost-effective strategy to protect human health and the environment in a challenging geologic setting.

Session 6: In-Situ Chemical Reduction (ISCR)

Implementation of Zerovalent Iron for Source Zone Treatment via Soil Mixing

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The soil and groundwater at a textile manufacturing site in Flanders is polluted with chlorinated solvents. Trichloroethylene is found in the groundwater in very high concentrations (426 mg/l). Much less 1,2-dichloroethylene and vinyl chloride has been detected in the groundwater. The pollution in the soil is only trichloroethylene. A pure product layer has been detected at a depth between 7,2 and 7,6 m bgl. The soil consists of sandy clay and the permeability is very low. Practice has shown that the source zone can't be removed by traditional techniques such as pump and treat. Excavation would be complicated because the pollution is situated near a building and at a great depth. To excavate the pure product layer expensive measurements are required. Because of this, excavation is not BATNEEC. In situ chemical reduction of the DNAPL by injection of ZVI (zero valent iron) may be a solution.

The chemical destruction of the chlorinated solvents by addition of ZVI was examined by VITO in lab tests. These tests proved a degradation of more than 95% at the dose that was selected for field application. After a period of 8 weeks, a carbon source to stimulate biodegradation was added. With the C-source, a further decomposition of the chlorinated solvents was achieved.

On large scale, it is often a problem to keep the iron in suspension during injection and to distribute the iron equally over the polluted zone because of the great density of iron and permeability limitations of the soil. To counter this problem, the iron was suspended in a guar gum slurry which was distributed in the subsurface by soil mixing. During drilling, the ZVI-slurry is injected under high pressure and mixed with the soil at the same time, creating a soil mix pile. At this particular case, a total of 14 soil mix piles were executed successfully until 8,4 m bgl, whereby 3500 kg of fine sized micro scale ZVI was applied. The guar gum will be biodegraded in time with release of simple sugars. This is expected to stimulate the anaerobic biodegradation of the chlorinated solvents, which would complement the chemical reduction by the ZVI.

The soil in the soilmix columns was sampled 12 months after soil mixing. The concentration decreased from 43700 mg/kg dm to 81,5 mg/kg dm. The concentration of iron in the soil is still high.

The groundwater concentrations measured until 12 months after soil mixing prove that trichloroethene is converted to the degradation products cis+trans 1,2-dichloroethene and vinyl chloride by the ZVI. Relatively high concentrations of ethene are measured. The groundwater and soil concentrations will be further monitored.

This pilot has already shown that soil mixing may be a promising alternative to injection of ZVI by direct push or by injection in wells. The soil mixing can be a solution for the treatment of chlorinated solvents in high concentrations in dense soils and at great depth without removing a lot of soil.

Site Closure using Enhanced Reductive Dechlorination with Large Diameter Treatment Columns on Two Chlorinated Sites

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Successful remediation of contaminated sites requires a significant understanding of the contaminant distribution throughout the site. Sites that have underlying geology that consist of low hydraulic conductivity soils and/or fractured bedrock are particularly challenging from a remediation perspective often times due to back diffusion of adsorbed contaminants from the low hydraulic conductivity contaminated media.

In the first case study, in 2009, a typical moderate to high-pressure injection grid array was used to implement an in-situ chemical oxidation (sodium and potassium permanganate) remedy unsuccessfully at a dry cleaner site in Aurora, Colorado, USA. In 2011, the monitoring well network was sampled and concentrations of tetrachloroethene (PCE) were recorded higher than at any time throughout the project history. This "rebound" played a pivotal part in the eventual closure of the site.

The second case study was a large commercial drilling equipment contractor maintenance facility that had a 26,000 gallon underground storage tank that was the collection vessel for drilling equipment degreasing and cleaning operations. Trichloroethene (TCE) was the primary degreasing solvent and after removal of the underground storage tank, primary and secondary remedial excavations were unable to remove all of the contaminant mass due to the shallow groundwater located in a sandy formation at 1.5-2 feet below the existing groundsurface.

This presentation discusses the evolution of the "Large Diameter Treatment Column (LDTC)" and demonstrates its effectiveness in both low hydraulic conductivity clays and weathered claystone bedrock, and in higher hydraulic conductivity sands. In addition, the LDTC has the complimentary "side" benefit of achieving discrete and precise excavation which can be significant due to the volume of the drilled borehole prior to completion.

The selected remedy in each case was Enhanced Reductive Dechlorination (ERD) using the amendment EHC-L® (Peroxychem) and zero valent iron creating an in-situ bioreactor within the LDTC boring. In the first site, multiple LDTC gravity injections were completed as well as microbial inoculation using Sirem® KB-1 cultures.

Both sites achieved closure, the first site receiving closure under the 2014 Colorado Department of Public Health and Environment's (CDPHE) "Low Threat Risk Closure Guidance" program and the second site, received "No Further Action" under CDPHE's Integrated Corrective Action Program (ICAP).

These and other aspects of each project leading to site closure will be discussed in this paper.

Reduction, Adsorption, and Precipitation of Heavy Metals by Elemental Iron, Iron Sulfides, and Related Reactive Minerals

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In situ chemical reduction (ISCR) has increasingly been applied to treatment of soil and groundwater contaminated with chlorinated organics. The mechanisms involved in such applications are now fairly well understood and widely recognized in the environmental remediation community. ISCR can be broadly defined as a category of *in situ* soil and groundwater remediation technologies in which treatment occurs primarily by chemical reduction of contaminants, mediated mainly by abiotic processes. It is also recognized that ISCR mechanisms of contaminant reduction can be stimulated by microbial activity (e.g., carbon fermentation), and even created solely by the activity of microorganisms (e.g., biogenic reactive minerals). The major groups of reductants operative in ISCR treatment of soil and groundwater can be broken into four groups including (a) elemental iron such as ZVI powder, (b) minerals that derive their reducing power from Fe^{+2} such as 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} such as pyrite, and (d) organic matter containing redox-active functional groups such as quinones. All the mechanims involved in ISCR degradation of chlorinated organics are now understood to be related to the transfer of electrons from a reducing agent (the electron donor) to an oxidized species (the electron acceptor). The same cannot, however, be said for the application of ISCR to treatment of heavy metals. The authors will present a survey of ISCR materials and mechanisms as applied to treatment of heavy metals in soil and groundwater.

Feedback on the Chemical Reduction; Application Modes, Efficiency, Technical Limitations, Compared to Oxidation. Is the Chemical Reduction Ideal for the Treatment of Chlorinated Solvents?

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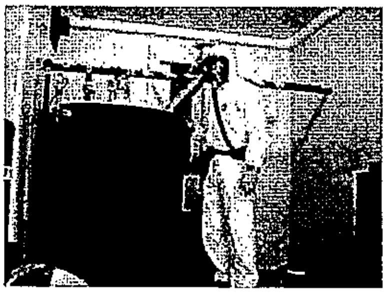
Key words: feedback, chemical reduction, technical limitations, oxidation, chlorinated solvents, vinyl chloride production, rebound effects, soil-mixing, direct injection, MIXIS®.

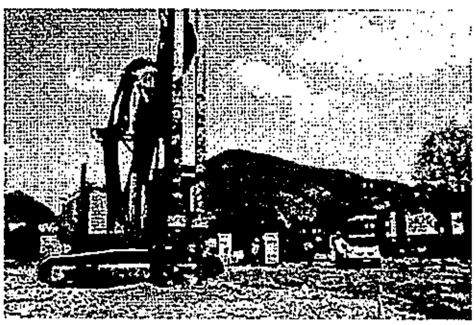
Traget: adapt and better design a chemical treatment solution of chlorinated solvents, taking into account the nature and chemistry of the soil, remediation targets and constraints of the site.



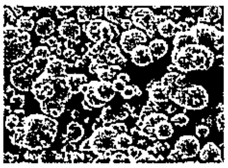
Chemical treatments, oxidation and reduction, are for many years, one of the pillars of the technics used for the treatment of recalcitrant compounds and mainly chlorinated solvents. These solutions have generally proven efficiency, but there are limits. These limits are of course linked to the reagents used, but also related to the nature of the soil, its geochemistry, the pollutants, or the mixture of pollutants encountered in the implementation of treatment and the achieved design...

The world of chemical processing is a complex world, because in the soil, many parameters are taken into account. What works well in a batch laboratory test does not always works as well in the field and this may even be the opposite, including reaction kinetics and inhibition problems.

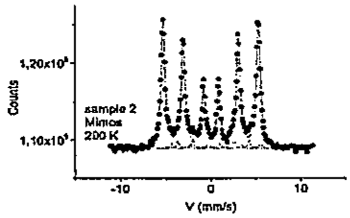
First of all, application modes of chemical reagents will be reviewed, such as gravity injection, hydraulic fracturing (direct injection or manchettes tubes), in-situ soil mixing. The advantages and disadvantages of each solution will be studied in the light of several projects feedbacks.



The effectiveness of chemical reduction is well established and when this is used wisely, the removal efficiencies are closed to 100% and without rebounds. However as any technical solution efficiency in soil, efficiency is a function of many parameters.

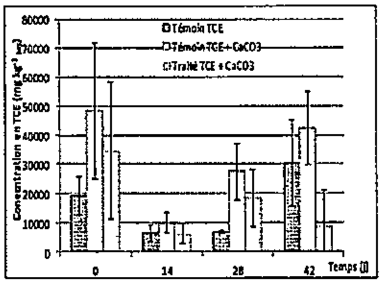


Many laboratory tests were performed an attempt to correlate this efficiency to the physico-chemical parameters of the zero valent iron, such as particle size distribution, specific surface, elementary composition, surface composition and zeta potential.



To do that, tools such as MEB and EDX probe or Mössbauer spectroscopy were used. This study has evaluated the effectiveness of various iron powder on dissolved pollutants and has defined the most appropriate environmental applications, but did not draw a direct link between the physical and chemical parameters of the studied powders and their effectiveness in the soil.

A feedback based on numerous laboratory tests, and several full scale projects, is then proposed to evaluate the effectiveness of chemical reduction with zero valent iron used as the main reagent. The observed performance differences were simulated in the laboratory in order to try to find the main criteria dictating the effectiveness of treatment.



It appears that certain criteria (non-exhaustive) studied partially inhibit degradation reactions of chlorinated solvents, such as carbonates and sulfates. But under these conditions is the concurrent solution (chemical oxidation) more effective? Are there others techniques?

In any case, it appears that the chemical treatment of soil and groundwater involves complex phenomena and that only a pragmatic approach, consisting in the realization of laboratory testing and field pilot tests, allows anticipating the effectiveness of the proposed technical solution.

Session 7: Delivery Techniques for In-Situ Remediation

Monitoring Injections at in Situ-Remediations by Geoelectrical Methods

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Kv. Renen 13 is a heavily contaminated former industrial site located in Varberg, SW Sweden. The major contaminants are trichloroethene (TCE, up to 20,000 µg/L) and trichloroethane, and their metabolites. Cadmium, chromium, zinc, and cyanides are also found within the area.

DCIP (DC resistivity and time-domain induced polarization) tomography was carried out at the site to investigate the geology and possibly to delineate the contamination. Via the resistivity results we have been able to identify a larger fracture zone, possibly transporting the contaminants towards southwest. With the induced polarization measurements we were able to identify a pilot test area for which an injection of 3D Microemulsion and HRC Primer (Regenesis, UK) has been carried out and by performing the same measurements in time steps we can monitor changes within this test remediation area.

DCIP tomography is a promising non-invasive tool for monitoring of in situ remediation of sites contaminated with chlorinated solvents. With DCIP the subsurface conditions can be mapped and monitored more costeffectively and in a more comprehensive way than by traditional investigation methods alone.

Innovative Technologies to Deliver Oxygen to Aquifers

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Aerobic bioremediation is a consolidated technology widely used for the removal of many organic contaminants, in particular for those of petroleum origin (TPH, DRO, GRO, BTEX, ...). This technology optimizes the ability of autoctonous bacterial strains to oxidize contaminants (electron donors) using oxygen as an electron acceptor.

The biological process can be limited by many factors such as dissolved Oxygen availability. When dissolved Oxygen is not available, bacteria will use other sources of oxygen (electron acceptor) such as nitrates (nitrification), sulfates and other oxidized species. These other sources of oxygen are thermodynamically less convenient and result in reduced rates of contaminant removal.

From a process point of view is therefore necessary to ensure a good availability of oxygen to stimulate the most effective aerobic degradation reactions. Most of the products that release oxygen are based on CaO_2 or MgO_2 and should be injected into groundwater in the form of diluted suspension (slurry), dense and difficult to inject.

As an alternative to peroxides Oxygel is a product in gel form of new concept that can be injected as it is at a very high concentration of available oxygen with respect of conventional diluted slurries. The easy and low-volume injections can greatly reduce the total cost (product and injection) and duration of field operations. The duration of Oxygel in the subsoil is equivalent to CaO_2 and MgO_2 based products.

Weidemeier et al. (1999) showed that over 70% of fuels natural attenuation are due sulfates reduction by sulfate-reducing autoctonous bacteria. Further studies have shown significant success in remediation hydrocarbons exploiting the capabilities of sulfate-reducing bacteria (Reinhard et al., 1997; Anderson and Lovely, 2000; Somsamak et al., 2001; Sublette et al., 2006). For this reason, in collaboration with Carus, Redoxtech (USA) has developed OBC+ an innovative product to stimulate sulfate-reducing bacteria by supporting their activities with nutrients and buffering the pH. As a side effect precipitation of dissolved metals in the form of insoluble and stable metal sulfides has been observed. The use of OBC+ results in unexpected high contaminants degradation rates even in presence of residual free phase (LNAPL).

We will present the different available technologies to improve aerobic bioremediation reactions (Oxygen release, sulfate reducing bacteria stimulation) along with cost comparisons and several case studies.

Keywords

Aerobic Bioremediation, Petroleum Hydrocarbons; Fuels, Oxygen Release, Sulfate Reducing Bacteria.

A New Device for Direct Liquid Injections in Subsoil: Results of a Pilot Test

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Since the 'invention' of *in situ* soil remediation, multiple techniques have been developed and applied to dose liquid or liquified substrates and chemicals in the subsoil. Besides recirculation of groundwater, liquid injection on fixed filters and soil mixing, direct push injections are frequently chosen for its limited operational cost and its flexibility in case of multiple injection rounds.

Although direct push injections are to date widely applied, the use of this technique has disclosed several drawbacks and limitations resulting from its design. First, since a large "injection needle" is pushed directly into the soil without prior augering, a heavy machine (or other counter weights) is needed, which, on its turn, impedes the employability of the technique in small buildings and basements. Second, as a result of the shape of the injection cone, the soil around the injection point is compacted resulting in a considerably lowered hydraulic permeability. Consequently, higher injection pressures are needed to obtain workable flow rates. These higher pressures can give rise to preferential channeling. Besides, the soil compaction around the injection point and along the entire length of the injection needle whether or not in combination with the vibrations of the rods when hammering is applied, gives rise to the formation of an upward (or downward) "highway" for the injected fluids. In extreme cases, this highway can result in so-called blow-out. As a result, one can never exactly know where the injected product really enters the surrounding soil.

As the importance of in situ soil remediation is still growing, research has been done to develop a new injection technique which can overcome the above mentioned drawbacks. A prototype of the device is constructed and multiple tests have been done.

Session 8: Risk Assessment

Direct Toxicity Testing for Contaminated Land Management

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Contaminated land management is generally based on the assessment of exposure and its comparison to the hazard of identified contaminants. Exposure is calculated from measured environmental concentrations by using transport and fate models and compared to the no effect threshold concentration of a single contaminant. This practice is based on the "chemical model", a rather poor representation of the environment. In the real environment pollution is typically caused by a mixture of unidentified contaminants and the actual adverse effect is largely influenced by environmental conditions (pH, Eh, humidity, etc.), the quality of the soil matrix and the living organisms present. The application of the chemical model in contaminated land management results that the healthy state of the environment must be translated into chemical concentrations after significant simplification. Furthermore from the chemical analytical results of environmental samples should be extrapolated back to the environment, to the possible deterioration of the ecosystem and human health.

Direct toxicity assessment (DTA) represents a shortcut between ecosystem response and risk management, making *in situ* might as well online toxicity monitoring and immediate intervention possible. DTA provides risk related information for a dynamic decision making based on the measured scale of adverse effects. It ensures high environmental relevance representing all possible interactions between contaminants, ecosystem members and soil phases aggregating the effects of the contaminants present in the sample. In addition to this, DTA can simulate different water and soil uses and real, multiple exposures related to single and several organisms or microbial communities. But, directly measured toxicity of environmental samples cannot be expressed in concentration, thus it does not fit the chemical risk assessment model, and cannot be compared to the concentration-based screening values applied in environmental management.

Applications of DTA for contaminated site investigation are introduced from authors practice and some innovative trials for the interpretation and use of DTA results for the management of the assessed contaminated sites:

- The application of *bioassay based threshold* values for treated soil reuse;
- The use of *effective soil dose* or *effective groundwater volume* and as an alternative the *effective sample proportion* to quantify risk;
- Using *No Effect soil Dose* (*NOEsD*), EsD_5, EsD_{20} or any acceptable and agreed scale of inhibition for setting site specific quality objectives;
- Interpretation of *Risk Characterization Ratio* as a ratio of the measured and the target toxicity;
- Interpretation of excess risk as a difference between the *RCR* values of contaminated and reference soils;
- Introduction of the *equivalency approach* for the "chemical" interpretation of toxicity results to bridge the gap between the chemical and biological toxicity models.
- Interpretation of the discrepancies between DTA and chemical analytical results.

References:

Gruiz, K.; Meggyes, T. & Fenyvesi, É. (Eds.) (2015) Engineering Tools for Environmental Risk Management: 2. Environmental Toxicology. CRC Press. ISBN 9781138001558

Method for the Assessment of Risks Due to the Permeation of Organic Contaminants through Polyethylene Drinking Water Pipes

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In many countries, drinking water quality is jeopardized by the permeation of contaminants from contaminated soil or groundwater through polyethylene drinking water pipes. The Dutch water companies use so-called signal value to identify potential risks for drinking water quality due to permeation. These signal values are much lower than the Dutch Intervention Values for groundwater. Intervention Values for soil and groundwater quality are used as a trigger value to identify potential risks as a result of contamination. It was questioned whether the Intervention Value provided adequate protection for the quality of drinking water. Both, signal values and intervention Values, are based on risk assessment modelling.

The National Institute for Public Health and the Environment and KWR Water Cycle Research Institute were asked to developed a new method for assessing the risks caused by the permeation of contaminants through drinking water pipes.

The core of this method is a step-by-step approach that should lead to sound decisions on adequate measures to be taken. The approach incorporates the use of risk-based trigger values for groundwater, a state-of-the-art model for the calculation of permeation and, if there is any doubt, the execution of verification measurements in drinking water.

In this study, the current methods according the Soil Protection Act and according the procedures of the drinking water companies were evaluated. Based on this evaluation the step-by-step approach was developed, together with a proposal for a trigger value to rule out possible risks.

For this procedure, also e a new model is developed to calculate the extent of permeation through the PE drinking water pipes. Subsequently, the practicality and the related uncertainties will be evaluated. The new permeation model will be used to derive risk limits for frequently occurring organic contaminants in groundwater. It is noted that the resulting risk limits are undergoing evaluation and require further improvement before implementation.

It is advised that the new assessment procedure replaces the current procedure and signal values. With the use of this procedure the risk assessment of permeation will be based on the same procedure and the same level of protection for both soil remediation as drinking water frameworks.

In this presentation the preliminary results of a procedure to assess the potential risks due to permeation through drinking water tubes will be expounded.

Innovative Remediation Technologies Applicable to Sites Polluted by Metallurgical Activities

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Soil pollution with heavy metals is a worldwide problem, pollutants having a complex impact by affecting the environment and human health. This study focuses on the area of Baia Mare, situated in the North-Western part of Romania that was a center of metallurgical activities. Baia Mare has a historical soil contamination with heavy metals like Pb, Zn, Cu, Cd and As, mostly due to the activity of metallurgical plants (mineral processing, nonferrous metallurgy and transportation). One of the biggest concerns is that the waste mine deposits and the polluted areas are very close to the residential areas. They destroy the landscape and affect ecosystem and population. Many years of mining and metallurgical activities affected the citizens' health, even nowadays suffering of different diseases and even a shorter life compared to other regions. The results obtained by evaluating the quality of the soil inside the plants from the area proved that the concentrations of metals are very high, Cu: 96 ... 7500 $mg.kg^{-1}$; Zn: 117 ... 7700 $mg.kg^{-1}$; Pb: 500 ... 48,000 $mg.kg^{-1}$ and they vary depending on the depth of sampling. Through the research conducted on experimental models resulted two innovative technologies of bioleaching (in situ and ex situ) applicable for the remediation of soils contaminated with metals. Experiments regarding in situ bioleaching indicated that, only 4 weeks after being treated, high depollution yields can be obtained. It was discovered that, in the case of copper, zinc and lead, the yield is much higher at surface samples of 10 – 20 cm and 20 – 35 cm. The bioleaching solution (9K medium) used has a very good efficiency for Cu: 52 … 92% and Pb: 59 … 90% extraction and good for Zn: 34 … 86%. Experiments regarding ex situ bioleaching have shown that, only 2 weeks after being treated, the following depollution yields can be obtained: Fe and Cr: 90%, Mn: 77%, Zn: 75%, Pb: 67% and Cu: 56%. In addition, our research focuses on determining the optimal conditions for the application of phytoremediation in the case of metal polluted soils. Further studies must be undertaken to prevent the dangerous substances entering the food chain and different remediation possibilities must be tested in experimental models and also in field applications.

Session 9: Sediment

Sediment Transport: From Academic Models to Industrial Tools

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Predicting sediment transport is of profound importance for the prevention and mitigation of environmental hazards. However, despite the intense efforts that have been devoted to the development of physical models with high predictive capacity, the state-of-the-art remains unsatisfactory. Moreover, communication and synchronization between academia and industry are both inadequate and dissemination of novel and innovative ideas are impeded.

In the first part of this talk, we quantify the primary reasons that have inhibited bringing the gap between academia and industry and propose viable solutions for the circumvention of extant obstacles. Particular emphasis will placed on the clarification of disparities between academic models, that aim to model the complicated physics behind sediment transport, and industrial tools, that pertain to the sufficiently accurate prediction of sediment transport.

In the second part of this talk, we will introduce a novel tool for the simulation of sediment transport that is currently under development in our laboratory. In contrast to the majority of existing sediment transport tools, our simulation suite predicates on a systematically reduced physical model for sediment transport that accommodates the most recent developments in the field.
As such, it is designed to capture most of the important characteristics of sediment transport in coastal and fluvial areas.

Following a demonstration of the predictive capabilities of our simulation suite, we will advert to possible extensions. More specifically, we will discuss the possibility of accounting for the presence of pollutants and associated chemical reactions, both of which are of elevated interest for the remediation society.

Design of a Large-scale Remediation Approach of a Heavy Polluted River

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Antea Group, Belgium

Throughout the years, industrial and domestic discharges in a local river, resulted in a 17 km long polluted river zone. A total surface of 63,5 ha is strongly polluted with heavy metals, chlorides and ionising radiation materials. The present pollution does not only effect the river water quality, but also the sediments, river banks and the surrounding area. Antea Group was selected to evaluate the possible remediation approaches and draw up a scope of work for this complex problem.

After further delimitation of the polluted soil and sediment, Antea Group was charged with the complex mission to find a balance between obtaining remediation objectives, prevention of structural damage to the existing valuable vegetation and peat log, the broader environmental plans for the whole valley, the practical implementation of the remediation works and the remediation cost. The river passes through several ecological valuable areas what makes the river, river banks and the surrounding area very difficult to access with heavy equipment, needed for possible remediation activities. An extended inventory of the terrain, the comparison of the different remediation techniques, the inventory of small scale dredging techniques for small, fast current rivers, combined with multiple consultations with the different involved stakeholders, resulted in a vast amount of data used to design a scientific based and generally supported remediation proposal for the different subareas and the different environmental compartments. For this, the BATNEEC-principal was implemented, but adjusted to the specific local conditions and problems. The classic evaluation frameworks were not applicable in the context of this project, because potential structural damage to the precious local environment could not be financially translated.

A project specific approach was developed in conjunction with the different involved actors and based on the extended practical experience of Antea Group.

The remediation approach consists of dredging the sediment and underlying riverbed combined with the installation of five sediment traps. The excavated sediment/soil will be removed by high-pressure tubing. At the transfer zones, the slurry will be drained by geotubing or laguning. The river bank and surrounding grounds will be remediated by a combination of an active (i.c. excavation and stabilisation) and a passive (i.c. phytostabilization and monitoring) technique, depending on the accessibility and the ecological value of the specific area.

By designing the remediation plan, a first important barrier has been taken to wipe out a historical environmental problem and to restore the area in its full ecological value.

Innovative Chemical Treatment of TBT (Tributyltin)-Impacted
Marine Sediments: A Bench Scale Study

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This paper focuses on a novel chemical reduction oxidation (REDOX) approach for the treatment of Tributyltin (TBT) present in contaminated marine sediments. TBT has been used globally since the 1950's as an inexpensive biocide and antifouling agent in marine paints to minimize aquatic organisms, such as barnacles and algae, from adhering to the hulls of ships.

Unfortunately TBT has since been determined to be very harmful to invertebrates and vertebrates, including humans, with toxic effects occurring at concentrations as low as 1 nano-gram per litre (1 ppb) of water for some species. Although TBT has been banned from use globally since the 1980's and 1990's, the presence and persistence of TBT in marine sediments is ubiquitous and poses an ongoing health risk due to the recalcitrant nature of TBT.

The bench scale study described in this paper uses a unique approach for the REDOX treatment of TBT to achieve trace to non-detectable concentrations in the treated marine sediments. This study also includes the degradation of associated chemical compounds; Dibutyltin (DBT) and Monobutyltin (MBT) with similar results.

Based on the findings of this study, our approach could be used as an effective methodology for the treatment of dredge marine sediments to reduce the TBT concentrations. In addition, it could allow for the sustainable reuse of the post-treated sediments in the environment.

Session 10: Sustainability- Driven Approaches for Decontamination – II

Evaluation of Social Aspects within the Sustainability Assessment of Soil Remediation Projects

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Sustainable remediation requires a balanced decision-making process in which environmental, economic and social aspects of different remediation options are all considered together and the optimum remediation solution is selected. Usually more attention is paid to the evaluation of environmental and economic aspects, in particular to reduce the human and environmental risks and to the remediation costs, to the detriment of social aspects of remediation.

This paper investigates, how social aspects are currently considered in sustainability assessments of remediation projects. A selection of decision support systems, used for the sustainability assessment of a remediation project, is analyzed to define how social aspects are considered in those tools. Additionally, the similarity of the considered social aspects with social indicators of the Sustainable Remediation Forum – United Kingdom (SuRF-UK), is addressed. The results are linked to expert's opinions and the suitability of the Social Life Cycle Assessment (S-LCA) as decision support system is also evaluated.

The consideration of social aspects in decision support systems is limited, only "human health and safety" and "neighborhood and locality" are frequently taken into account, while SuRF-UK identified five indicators to facilitate a holistic consideration of social aspects of a remediation project. The experts interviewed confirmed, that in practice, less attention is paid to social aspects; in fact it is mainly limited to health, safety and nuisance,. The S-LCA has the potential to assist in the evaluation of social aspects of a remediation project However, a simplification of its methodology is necessary, and further research concerning this matter is recommended.

Embedding Sustainability in a Practical and Easy Way during the Implementation of Remedial Projects

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Nowadays sustainability is highly ranked on the global trendy topics billboard. However, the implementation of sustainability-driven approaches during management of contaminated sites in Belgium remains limited, often still seen as an additional cost rather than a favorable lever.

Step by step, ERM is embedding sustainability in the implementation of Contaminated Site Management (CSM) projects, aiming for a balance between the efforts needed to enclose sustainability and the potential achievable added value.

ERM will present two sustainability assessments that were performed in 2014 during the implementation of remediation projects in Belgium. With the support of basic monitoring tools, Health and Safety (H&S) observations and CO2 impacts have been continuously monitored, assessed and discussed on a weekly basis throughout the remedial works. In parallel the monitoring tools as well as the remedial works were revised and adjusted where possible.

These dynamic sustainability assessments allowed to characterize the magnitude and distribution of the project impacts during the execution of the works, and to identify specific key factors on which focused effort could invested to improve environmental and social factors during project execution (e.g. optimization on cement or carbon source use).

On a broadened horizon, communicating results and findings is crucial to increase the general understanding of the benefits of implementing sustainable approaches. ERM will continue to replicate these assessments on new projects, starting from planning and design stages. Collateral positive outcomes such as the development of diversified tools (to cover new techniques, well-being, communication, etc.) and an increased stakeholder's engagement are expected. All together these contribute to further embed sustainability in a practical and beneficial manner in CSM projects.

Cost-Effective Site Remediation Strategies: A Community-Supported Sustainable Model that Works with Even a Limited Budget

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Background/Objectives: Past operations at an industrial manufacturing facility in Alabama resulted in the release of chlorinated solvents into the subsurface. The current site owner of this 12 acre property is a small municipality with a limited budget requiring that technologies used throughout the project life-cycle are optimized to provide the highest return of information and results on expenditures. Facility operations where solvents, including PCE, TCE, and vinyl chloride, were utilized were investigated using passive soil gas techniques. This high-resolution site characterization approach determined the presence or absence of contamination, defined highest concentrations and delineated the lateral extent of contamination. The technique provided superior information for planning remedial activity. Remedial approaches including phyto-remediation, chemical oxidation and soil vapor extraction were utilized to lower soil and groundwater contaminant concentrations

Approach/Activities: A minimally intrusive, passive soil gas (PSG) technology was used to define the nature and extent of chlorinated hydrocarbon contamination across this industrial facility. An initial survey was performed to target three areas of concern (AOCs) where chlorinated solvents were identified in groundwater. A 25-foot PSG sampling grid was established, totaling 148 sample locations, with minimal confirmatory samples required to confirm baseline concentrations. A strategic plan removed the obsolete buildings, contained the contamination on-site, and enhanced the natural attenuation of the chlorinated solvents through phyto-remediation augmented with chemical oxidation in select hot spots and soil vapor extraction. The two hot spots were remediated utilizing in-situ chemical oxidation. As an alternative to other more intrusive and costly remediation approaches, the combined approaches were developed to deal with varying levels of contamination. The local municipality and environmental agencies supported the approach.

Lessons Learned: The strategy employed using low-cost, highly effective methodologies to characterize and remediate subsurface contamination is a model easily applied to sites with limited funding, but also to a multitude of sites as a cost-effective strategy. Both the local municipality and regulatory agencies supported the multi-year sustainable strategy to remediate environmental contaminants, improve the property physical appearances, and accomplish reuse. The site contains new phyto-remediating greenways that connect to corridors to 2 local community schools. Analytical data will demonstrate the reduction in contaminant levels as a result of the remedial approach, while containing contamination on-site. Graphical data will present groundwater elevations and hydraulic control achieved. The initial treatment area achieved a 99% contaminant concentration reduction after 5 years. A 2nd area of concern achieved a reduction of 87 % after 2 years. Pictures of the site will be provided to illustrate the esthetic and functional improvements to the property. The integrated methods utilized in the remedial plan reduced cleanup costs by 2 million dollars when compared to a traditional excavation action. A discussion will be presented on the remedial approaches that were used, including a blend of traditional, as well as innovative products.

Review of Decision Support Tools for Sustainability Assessment of Site Remediation

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The paper presents a literature review of existing decision support tools applied in the context of contaminated site remediation. Many of these decision support tools claim to approach remediation projects from a sustainable point of view. In the last few years, reviews have been published on the application of Life Cycle Assessment (LCA) for the evaluation of site remediation options (e.g. Cappuyns, 2013), but economic, as well as related social aspects are not or only marginally addressed, whereas their importance in the overall sustainability appraisal of site remediation projects is highly recognized. Because intensive research on LCA has already been performed, this tool is excluded from the set of decision support tools analyzed in this paper.

Based on the Brundtland report (World commission on environment and development & Brundtland, 1987) five critical elements of a sustainable decision support tool are defined, which serve as a standard for the assessment of the different decision support tools. The five elements consist of the extent of integration of the economic, environmental and social aspects of sustainability, the time dimension and how the tools handle economic and technical uncertainty. The specific contents of the five chosen elements are based on scientifically proven frameworks (SuRF-UK) and principles. The main attributes of all the analysed decision support tools are shortly described and an assessment of these decision support tools based on the five key elements is presented. To conclude the 'real' sustainable tools are listed and the a recommendation for users, including an extra element for practicality, is provided.

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Session 11: Site Characterization and Remediation-II

MIP-In - Combined Detection and Treatment of Pollution: A First Large Scale Pilot

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MIP-in is an innovative remediation technique based on a combination of the detection of pollution and real time remediation thereof, through injections. The detection of contaminants on site is done with a membrane interface probe (MIP), which allows for the detection of a broad range of volatile organic contaminants. The remediation is performed by means of direct push injection of reactive products.

The first trials of the MIP-in concept have been designed and carried out within the FP7 Upsoil; further trials were executed in the FP7 Aquarehab. In September 2013 a designated Eurostars project was started for the further development of the MIP-in technique, which is a collaboration between ABO (Belgium), VITO (Belgium), Dekonta (Czech Republic) and Ejlskov (Denmark). Within the Eurostars project three small pilot tests were conducted in Denmark, Czech Republic and Belgium, to improve the MIP-in setup. To develop and assess a dynamic approach for applying MIP-in in realistic conditions, a semi full-scale pilot test was performed in Belgium. This semi full-scale pilot will be the topic of this lecture.

On a site in Ghent, provided to us by the Flemish Waste Agency (the OVAM), a pollution with chlorinated solvents in the groundwater was present; caused by a chemical factory. Since the detection and delineation of the contamination, a large redevelopment project had been carried out on the site. This included extensive dewatering and caused the removal of all relevant monitoring wells. A few MIP's, carried out in 2012, was the only available recent data; while it was expected that the location of the pollution could have shifted due to the dewatering. This uncertainty of the precise location of the pollution made the site ideal for testing the MIP-in technique.

Based on lab tests it was decided that enhanced reductive dehalogenation would be a feasible technique for the remediation of the pollution. The product 3DMe (by Regenesis) was selected, mostly because of its longevity. A preliminary conventional (non-MIP-in) design was made, as a kind of approach one would follow if a certain budget was available for a big pilot test. This preliminary design serves as a reference to which the results of MIP-in can be compared.

Using MIP-in, the injected volumes were determined in function of the detected XSD-response; the volumes ranged between 20-120 liter per 30 cm interval. At depths where no significant XSD-signal was observed, no injection was performed. Also, the location of every next MIP-in point was determined based on the XSD-results at the MIP-in points that had already been executed.

Within 12 days, 22 MIP-in injections were performed, as well as two regular direct push injections for comparison. 21,000 liter of solution was injected, containing 2,100 liter 3DMe. A comparison was conducted between the effectively injected volumes using MIP-in and the designed volumes with a traditional approach. For this specific case, this shows that with a traditional direct push approach, one would need approximately 75% more reactive product compared to the MIP-in approach, to obtain similar effectivity.

Large Scale Systematic Mapping and Prioritization of Possible Soil Contaminations – A Method to Protect Drinking Water Resources, Surface Water and Human Health in Denmark

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Background:
Soil pollution poses a continuous threat to the Danish groundwater. The groundwater is the primary water resource suitable for drinking water in Denmark, and currently the only one used. Several years of infiltration through the ground has filtered the water, and thus a minimum of treatment is required in order to achieve drinking quality standards. If one or more contaminations are left unnoticed this could potentially affect entire drinking water catchments, and, worst case, shut down drinking water extraction from an entire catchment for years. Therefore, thorough mapping and prioritization of further action at possibly contaminated sites are crucial. This allows an optimal foundation for further actions, remediation and mitigation of contaminated sites to secure clean drinking water.

Using a large scale systematic approach to map and prioritize soil contamination, requires the authority to be able to control both funding and execution of exploration and investigation. In Denmark, the five Regions of Denmark, including the Capital Region, are the authorities of soil and groundwater, and at the same time fund the investigations and remediation of soil and groundwater. As of November 2014 additional funds have been allocated in order to obtain clean groundwater in the Capital Region more rapidly.

Every year the Capital Region of Denmark spends around 22 million EUR on contaminated soil and groundwater. There are approximately 6.400 contaminated or potentially contaminated sites in the Capital Region, and more sites are still being registered. If the contamination threatens either groundwater or indoor climate, the Capital Region is obliged to remediate or mitigate, so prioritization is necessary to ensure that the funds allocated for protection of the environment and human health are spent optimally. The prioritization procedure includes all steps; from preliminary investigations of historical data through delineating investigations to design and execution of remediation and mitigation.

Strategy:
Locating possibly contaminated sites through historical investigations is step one. A systematic examination of historic data identifies industrial activities that typically result in soil and groundwater contamination. The historical investigations are implemented in areas where groundwater has high priority due to high water quality and quantity and in catchment areas. Every tool at disposal is used, such as data from old phonebooks, municipal archives, aerial photos and directories. Several years of knowledge of various industries has been put into industry descriptions. These allow for pinpointing of possibly contaminated sites based on activities and industries found on sites in the historical investigations. There is a constant focus on keeping the industry-descriptions up to date. This is done through regional collaboration, exchange of experience and gathering new information. This knowledge is critical since every contamination

not found will not be included in the subsequent prioritization and risk assessments, and will be left to possibly affect large quantities of groundwater.

The sites that are historically registered as possibly contaminated will be investigated in the field with an environmental preliminary survey. The sites are prioritized with regard to ground- and surface water threats, and indoor air quality threats. Thus industrial activities known to use chlorinated solvents are investigated first. The preliminary survey includes a predefined method for groundwater, soil and soil gas sampling. The sites with contamination that represent a threat to groundwater and/or indoor climate will be prioritized for delineating investigations, followed by prioritized remediation and mitigation.

All information on the possible and confirmed soil contaminations is registered in a national database, to maintain an overview. This database allows for a review of the registered sites, and future adaptation, should changes in prioritization occur, or as more experience is gained or new methods developed. It also makes it possible to generate specific publically available databases on the contamination situation at individual sites, for citizens to use in i.e. property sales.

Conclusion:
A large scale systematic approach such as this, is viable as long as the authority controls both funding and execution. The yearly budget does not enable the Capital Region to investigate all contaminated sites in the region at once. With the extra funding allocated in 2014, the current objective is to protect 80% of the groundwater within a 10 year timeframe, while still ensuring safe indoor climate. With this systematic approach it is possible to handle thousands of potentially contaminated sites, and through historical and environmental investigation, gradually reduce their number to a few hundred that ultimately need remediation, in order to meet the 10 year deadline.

Applying the Triad Approach for Effective On-Site DNAPL characterization and delineation: a case study

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DNAPL (Dense Non Aqueous Phase Liquid) can dissolve for a long time into the aquifer and might therefore jeopardize the holistic remedial strategy of the site if not correctly investigated.

An on-site DNAPL (chloroethenes and chloroethanes) characterization study was performed at an industrial site in Wallonia in order to optimize the remedial design of the DNAPL. ERM developed a phased approach investigation consisting of :

1. Collecting undisturbed soil samples around wells were DNAPL was previously encountered;
2. Evaluating the depth were DNAPL was present by screening the soil liners (Geoprobe liners) with a PID;
3. Testing the most contaminated horizon using a hydrophobic dye, called Oil Red O to visually determine the presence of DNAPL; and
4. Collecting representative soil samples using menthol vials and analyzing them for mass quantification and delineation purposes.

The results allowed to delineate vertically and horizontally the pure product extend as far as possible, considering site restrictions and accessibility. This approach allowed to develop a more targeted remedial action plan, reducing costs and optimizing effort.

Optimizing Reconciliation Quality between Characterization and Remediation Soil Volumes/Masses: Feedback on Real Cases and Key Success Criteria

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The global economy of remediation projects is strongly impacted by the quantity of soil to be excavated, treated, then re-used or eliminated. Among other approaches, geostatistics provides relevant solutions for site characterization as illustrated in a previous project funded in 2012 by the French cooperative research network on waste and environment composed of industrial and institutional members (RECORD): "Critical feedback about the use of geostatistical methods for characterization soil pollution". However, whatever the relevance of the characterization approach, discrepancies may still exist between contaminated soil volumes estimated during the characterization phase and the reality of the remediation. Such errors can be explained by various factors: insufficient data, inadequate understanding of the pollution context, etc.

Within this framework, a new RECORD project aimed at assessing, using feedback from 25 industrial sites, the most relevant criteria that may ensure the consistency between characterization and remediation estimates. Reasons explaining the quality of predictions or on the contrary the presence of significant errors in terms of contaminated volumes estimates are precisely discussed: quality / quantity / nature of characterization data, pollution characteristics, methodology applied to estimate contaminated volumes, remediation type, control of the remediation efficiency, etc.
This analysis has been interestingly completed by a survey among actors involved in site characterization/remediation. This survey highlights their perception about the criteria leading to inconsistencies between characterization and remediation, the level of magnitude and the frequency of such inconsistencies. Operational advices are finally given in order to improve the estimation of contaminated volumes and remediation costs.

Session 12: Remediation via Physical and Thermal Techniques-II

Mixture of High and Low Boiling Compounds in a Mixed Low and High Permeable Setting – Thermal Design Considerations

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A 1750 m^2 site heavily contaminated with a variety of chlorinated components is to be remediated. The chlorinated compounds mainly consist of Vinyl chloride, Trichloroethylene, 1.2 Dichlorobenzene, Chlorobenzene and 4-Chloro-2-Methylanilin 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. The challenge is 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 ISTD in the unsaturated zone will been implemented. The target treatment temperature for both unsaturated and saturated zone is 100 °C. However using ISTD in the unsaturated zone will ensure part of the unsaturated volume to be heated well above 100 °C and in that way ensure a lower average concentration of the higher boiling compounds.

The purpose of the talk is to show the audience the different steps and design considerations in the final design and implementation of the solution. Two thermal models have been used to design steam injection and ISTD heating. Commissioning of the facility is expected to take place during July 2015 and operation is expected to start by the beginning of August 2015.

Thermal Desorption Technology for Remediation of Brownfields: Behavior of Various Types of Contaminated Matrices in Vacuum TD Unit

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The aim of the project named "Decontamination of brownfields extensively contaminated by organic compounds and heavy metals" is to find an optimized solution for soil and groundwater treatment at various brownfield sites. Soil treatment is realized mainly by ex-situ thermal desorption with combination of catalytic incineration.

Thermal desorption is a two steps process: (1) volatizing the organic contaminants by heating of the contaminated material and (2) treating the exhaust gas to prevent emissions of the organics. The main advantage of thermal desorption method is its high efficiency and process speed. Main disadvantage is its second step - need of the off-gas treatment. Heating up the soil and processing of the off-gas by incineration or condensation needs a lot of energy which makes the technology quite expensive.

In a first phase of the project different types of model and real samples were studied. Model samples included defined soil, clay, sand and peat contaminated by oleic acid, toluene and 2,2,4-trimethylpentane respectively. Real samples included rubble, oil sludge, filter cake, coal tar and black soil contaminated by different types of contaminants as pesticides, hydrocarbons, fuels or heavy metals. Desorption tests were not focused only on process efficiency but the main goals were to monitor the off-gas quality which is very important for catalytic incineration and to see matrices' behavior e.g. sintering, lumping etc.

Our results show high concentrations of sulfane, methane, hydrogen and also sulfur oxides, carbon monoxide or even nitrogen oxides. In case of pesticides possible formation of dioxins must be taken into account. These gases can be dangerous for the process – poisoning of the catalyst or risk of explosion, health and for the environment. Besides of these, we have also experienced hard crusts, lumps and other complications connected to the properties of the input matrices.

Efficiency of the desorption process for mentioned contaminants is above 95 %, off-gas quality differs based on quality of the input material. The concentrations of hydrogen, methane, oxygen, carbon dioxide, carbon monoxide, sulfur dioxide, sulfane, nitrogen oxides and total organic carbon (TOC) were analyzed. In some cases dioxins and heavy metals were also analyzed in the off-gas.

Authors would like to acknowledge the Technology Agency of the Czech Republic for its financial support (grant no. TA04020700).

In-Situ Thermal Remediation (ISTR) with Thermal Conductive Heating (TCH) and Steam Injection during Land Recycling and Beneath Buildings

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In-situ thermal treatments are applied successfully at several sites worldwide. In the past, several projects had been conducted with a moderate to low interaction with neighbours, structural engineering or industrial production processes. However, ISTR projects can be conducted as well under more complex boundary conditions. To enable successful ISTR projects under these complex conditions, interaction with other specialists must be coordinated usually by the remediation management team (RMT) additional to the remediation works. For example, the RMT has to coordinate as well the structural engineering (like foundation and superstructure works) to enable ISTR during land recycling projects.

Furthermore, more complex boundary conditions might affect ISTR design, operation procedure and measurement devices during the remediation. This lecture will illustrate the management of complex boundary conditions by referring on specific project references.

Example 1: In-situ thermal Treatment during simultaneous foundation and superstructure works for a new factory building
A VOC contamination was determined in low permeable (cohesive) silt and clay layers below an existing factory building in the groundwater fluctuation zone up to 8 m bgl. Due to changes of site owner's facilities, this existing building was demolished and replaced by a new factory building. The removal of the VOC source zone must be quick, deadline compliant and efficient. In-situ thermal treatment was evaluated as the most economical and efficient technology. The ISTR of the VOC contamination was realised with the THERIS method (thermal wells, conductive heating). But, ISTR works were not allowed to disturb foundation works or superstructure installation for the new building.

Thus, a close interface management between involved specialists for the installation of the new building like pile foundation team, superstructure construction team and remediation specialists was established to enable failure-free operation of each lot.

Building activity was conducted close to the remediation area. Remote controlled automated monitoring systems for remediation process relevant parameter like subsurface temperature, pressure and concentration and discharge in the SVE were established to enable a detailed remediation management. Coordination with other specialists as well as with authorities was implemented on a weekly base. ISTR was completed after 4 months with no disturbance of the new factory building installation.

Example 2: Steam enhanced extraction (SEE) beneath a building during industrial production
During the 1990s, a 'cold' soil vapour extraction recovered several kg VOC during a seven years operation. Nevertheless, remaining VOC contaminations were located in stratified sandy and cohesive silty layers beneath an industrial building up to 10 m bgl mainly in the saturated zone.

Source zone removal including permanent production in the building was only possible by installing steam enhanced extraction (SEE). To avoid VOC downward mobilisation, air was added to the injected steam (TUBA method). The steam-air injection was applied beneath the building into the contaminated groundwater. An interference of the production line due to the in-situ thermal treatment had to be avoided. Remote controlled automated monitoring systems were used as well to monitor boundary parameters like indoor air. It could be demonstrated, that indoor air intrusion of VOC was a process during the past years from the remaining source zone beneath the building. It could be reduced significantly by steam injection.

In both examples, mass flux during ISTR was significantly higher than during conventional SVE or Pump and Treat. ISTR enabled a soon remediation success during months including the installation of a new factory building or rather a continued industrial production in the building above the remediated source zone.

Experimental Investigation on the Physical Removal of Chlorinated Solvents by Adsorption onto PlumeStop™

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Groundwater is one of the most important drinking water resources in Europe, but, during the past decades a variety of pollutions and contaminants have been detected in groundwater, including heavy metals, halogenated hydrocarbons, chlorinated solvents and etc. Contamination of groundwater by chlorinated aliphatic hydrocarbons (CAHs) can have long-term adverse effects on human health and environment. CAHs are the most common source of DNAPLs (dense non-aqueous phase liquids) contamination. Due to their high density compared to water, DNAPLs migrate downward through the saturated zone often producing persistent, slow/releasing source zones. Since the mid-1990s, strategies for source removal and plume containment were becoming a big challenge for companies and researchers. This urgent need has led combining different remedies to find low cost, fast and eco-friendly strategies for efficient and sustainable CAH contaminated groundwater management. In the case of CAHs, due to their high toxicity, the rapid reduction of their concentration is often required in order to lower the risk associated with their migration.

Our research group has been involved in the development of the remediation strategy at an Italian CAHs polluted site characterized by a low and persistent level of contamination, mostly due to back diffusion processes from low permeability zone. Based on an extensive microcosm study of the site biological reductive dechlorination was recognized as a potential approach for the site remediation but the extremely low CAHs concentration and the consequent kinetic limitation made it not feasible for the site. An interesting option was identified in the use of the PlumeStop Colloidal Biomatrix (Regenesis Company). The product, essentially a micrometer activated carbon, should be easily injected in the contaminated aquifer creating an *in situ* adsorption zone which should be able, on one hand, to quickly reduce CAHs concentration (management of the potential risk) and, on the other hand, to raise up the kinetic of the biological reduction locally increasing the CAH concentration (at the carbon surface).

This report contains the results from an eight months laboratory investigation on the physical removal of chlorinated solvents (PCE and TCE) from contaminated water flowing through two different porous mediums previously flushed with Plumestop™ solution in order to coat the exposed surface with the sorbent matrix. Experiments were performed in a column configuration by using two Plexiglas columns (one column packed with coarse sand and the second one with a mixture of coarse sand and a fine fraction sieved from an aquifer sample collected at a site under investigation) and saturated by tap water for several days. The two different porous mediums were chosen as representative of the range of the aquifer characteristics at the investigated site, in order to verify the applicability of the PlumeStop™ colloidal matrix in the different materials. Preliminary experiments performed on the two porous mediums, without the presence of PlumeStop™, have revealed their negligible adsorption capacity. Each column was equipped with ten sampling ports equally distributed along the column length to allow sampling at different distance. Bromide tracer test has been performed on each column in order to characterize the fluidodynamic of the experimental systems. After the preliminary saturation and tracer test, columns were equilibrated for around two weeks with a solution containing PCE and TCE at a concentration around 1 mgL^{-1}, respectively. As far as fluidodynamic properties of columns are concerned, we estimated a required feed concentration at each column at ca. 2000 mgL^{-1} PlumeStop™ solution and total volume of around three column pore volumes. After nine days column's feeds were switched to a solution containing chlorinated solvents. Influent and effluent samples were then collected on a daily base; moreover, different column profiles have been determined for each column at three different operating times. The experimental results from the column packed with coarse sand, have shown how dissolved concentrations of PCE and TCE dropped to non-detectable level already at the first sampling port and remained the same through the rest of the test. As for the column packed with finer porous medium, contaminant reduction happened again at the first sampling port but the removal until non-detectable level was reached after approximately five pore volumes of chlorinated solvents passed through the column. Probably the initial phase was due to heterogeneity in the permeability of the column packing due to the presence of a mixture of larger and finer porous medium.

In conclusion, the laboratory investigation has clearly evidenced a fast and quantitative CAHs removal from the water phase due to sorption onto the PlumeStop™ coated porous mediums. After a short initial period, both columns behaved similarly indicating the good applicability of the colloidal matrix in a quite large range of grain size distribution. The experimental results have been used for the planning of a large pilot test at the investigated site. The test has been already approved by the local administration and it is planned for the next October.

Session 13: In-Situ Bioremediation-II

An Innovation to Increase Rate and Performance of *in situ* Bioremediation – Concept Tests and Full Scale Application Case Studies

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Bioremediation is now an established remediation approach widely used around the world. However, since its early adoption in the 1970s and 80s, there have been relatively few innovations within the sector beyond the increasing sophistication of electron donors and acceptors, and ancillary developments such as improved measurement technologies. Notwithstanding these, the technology remains challenged by a number of factors, from the forefront of which may arguably be singled out two perennial, core issues:

- **Bioremediation takes time** – despite great headway being made, it remains a relatively slow technology;
- **End-points remain uncertain** – whilst bioremediation may be employed with confidence to efficiently and inexpensively reduce contamination by one or two orders of magnitude, the (linear) rate of destruction characteristically decreases with time, leading to uncertainty of predictable performance against very low clean-up targets.

This paper presents a new innovation designed to address the above challenges. The technical innovation allows for wide area low-pressure dispersion of a sorptive medium through the aqueous subsurface primary porosity. The medium has a dual function; it sorbs contaminants, quickly removing them from the mobile phase, and provides a high surface area matrix favorable for microbial colonization and growth. Contaminant availability within a risk pathway is therefore reduced while at the same time contaminant destruction is accelerated.

Upon reagent injection, target contaminants partition out of the aqueous phase and into the reagent, thereby removing mobile contaminants from the immediate risk pathway. Concentration of the contaminants in this manner, in a matrix conducive to degrader colonization and activity, results in a direct increase in the overall instantaneous rate of contaminant destruction, given the quasi first-order biodegradation kinetics characteristic of environmental systems. This phenomenon can be doubly important at low contaminant concentrations, which may otherwise prove insufficient to support appreciable growth and activity of a degrading microflora.

The technology can be employed to inhibit spreading of contaminant plumes, to protect sensitive receptors, or to prevent contaminant migration across property boundaries. The technology is also postulated an effective tool for control and treatment of groundwater contamination associated with low-permeability porous formations and matrix back-diffusion, promoting diffusion out of the immobile porosity while preventing groundwater impact.

Field studies confirm wide-area dispersion, with order of magnitude (>90%) dissolved-phase concentration reductions secured at the test sites post-application sampling, increasing to two orders of magnitude (>99%) within two months for both chlorinated solvent and hydrocarbon species alike. Laboratory and field data provide confirmation of post-sorption degradation enhancement, with laboratory data describing a significant increase in the rate of contaminant destruction in biotic matrix systems compared to abiotic matrix and biotic non-matrix controls. Examples of commercial bio-project timescales competitive with ISCO are presented.

It is anticipated this technology will be of interest to users, prescribers and regulators of bioremediation alike, who may be confronted by the concerns stated above. The technology may be particularly welcomed by those challenged by back-diffusion and performance-tailing issues in dual-porosity or mixed-permeability sites.

Bioaugmentation for the Removal of High Concentrations of CAH in Groundwater

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At a contaminated site (Tessenderlo, Belgium) a groundwater contamination with chlorinated aliphatic hydrocarbons (CAH) is present. These compounds are very difficult to remediate because of their physical and chemical characteristics. In most cases, traditional remediation techniques are often inadequate, time-consuming and expensive.
Several years of research resulted in an innovative in situ bioremediation technique that is currently demonstrated on full scale (project of the EU LIFE+ programme: LIFE08 ENV/B/000046 LVM-Biocells).

In this project a unique multispecies dechlorinating microbiome (Mulidechlorobac) that degrades 1,2-dichloroethane (1,2-DCA), 1,1,2-trichloroethane (1,1,2-TCA) and chlorinated ethenes is applied. Pilot tests were executed to confirm the performance of Multidechlorobac in the field and to investigate the survival of the dechlorinating bacteria. These tests resulted in high removal rates of the CAH. Currently, the upscaling of the bioaugmentation technique for the site of concern is prepared. Furthermore, the feasibility of an anaerobic bioreactor for the on site growth of the culture in groundwater is examined. First, the growth of the dechlorinating bacteria in contaminated groundwater is investigated on labscale. The next step is the design of an anaerobic on site bioreactor. An overview of the obtained results will be presented together with the future actions.

Biostimulation of Fungal and Eubacterial Autochthonous Communities to Improve Biodegradation of High MolecularWeight PAHs in an Aged Creosote-polluted Soil

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On aged historically polluted soils, bioremediation may be strongly constrained by many limiting factors; among them, bioavailability of pollutants and degradation competence of the indigenous microbiota are of primary importance. High recalcitrant characteristics and low bioavailability rates due to aging processes can hinder high molecular weight polycyclic aromatic hydrocarbons (HMW-PAHs) bioremediation in real industrial polluted soils. Commonly, the application of classical biostimulation technologies by means of inorganic nutrients and surfactants amendments to polycyclic aromatic hydrocarbon (PAH)-contaminated soils does not remove the excess of the HMW-PAHs fraction. Taking into account the metabolic capacities of white-rot fungi coping with HMW-PAHs, mycorremediation arises as an attractive alternative to this kind of polluted soils. However their bioaugmentation has been extensively assayed on industrially-polluted soils polluted soils, but with controversial results.

Initially, in a bioremediation study, carried out with a historically heavily creosote-polluted soil (8500 mg TPH · kg^{-1}), it was revealed a high PAH-biodegradation capability from autochthonous microbial populations, reaching 80% of TPH biodegradation by aerobic biostimulation. However, benzo(a)pyrene and other five-ringed PAHs still remained unaltered (Viñas et al., 2005). Cyclodextrin-mediated mild extraction assessment revealed that only three-four ringed PAHs fraction were the bioavailable fraction which was utilized by autochthonous biostimulated bacteria (Sabaté et al., 2006).

With the aim of reducing the residual fraction of HMW-PAHs in aged-creosote-contaminated soil remaining after a 180-d treatment in a pilot-scale biopile, either biostimulation (BS) of indigenous Eubacterial and Fungal microbial populations with a lignocellulosic substrate (LS) or fungal bioaugmentation with two strains of white-rot fungi (WRF) (i.e., *Trametes versicolor* and *Lentinus tigrinus*) were also comparatively tested. The effect of the utilization of mobilizing agents (Soybean oil and non-ionic surfactant such as Brij 30) on biodegradation and native microbial community were also studied (Lladó et al 2013). The results revealed that soil colonization by both

WRF strains was clearly hampered by an active native soil microbiota. In fact, a proper enhancement of native microbiota by means of lignocellulosic substrate (wheat straw) amendment promoted the highest biodegradation of HMW-PAHs, even of those with five aromatic rings after 60 days of treatment. In this respect, possible mycoaugmentation approaches, might fail due to the LS-promoted growth of indigenous fungal and bacterial populations. It is also noteworthy that well known HMW-PAH-degrading bacteria, basically Actinobacteria (*Mycobacteriaceae*) and Bacteroidetes (*Chitinophagaceae*), and PAH biodegradation activity, were specifically inhibited after non-ionic surfactant Brij 30 addition (Lladó et al., 2015). A deep microbial community assessment by means of 16Sr RNA/ITS1-based pyrosequencing revealed that that Alpha and Gammaproteobacteria were the most abundant bacterial phylotypes in biostimulated soils, whereas *Fusarium* and *Scedosporium* were the main fungal genera in biostimulated and bioaugmented soil experiments . Major bacterial community shifts were caused by the type of mobilizing agent added to the soil and, to a lesser extent, by the addition of lignocellulosic substrate.

Our results show the importance of implementing bioremediation experiments combined with autochthonous soil microbiome assessment (16S rRNA-based Pyrosequencing/MiSeq) to gain insight on the effect of crucial parameters (e.g. use of additives) into the whole microbial community.

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Synergy of Trap&Treat BOS 100® and 3DMe Tackles Large TCE Plume

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A large manufacturing facility used vapor degreasing in the 1970s and 1980s that resulted in Chlorinated Volatile Organic Compound (CVOC) contamination of limited soil and widespread groundwater areas. In the Primary Source Areas, Trichloroethene (TCE) concentrations in groundwater exceeded 50 mg/L and rapid cleanup was required. Pilot testing of Trap & Treat BOS 100® (BOS 100®), a specialized catalyst manufactured by Remediation Products Inc., demonstrated the ability of this product to effectively and quickly reduce the source area mass. Biostimulation was selected for treatment of the Secondary Source and Dilute Plume Areas and involved injection of Regenesis' 3-D Microemulsion (3DMe®). The 3DMe® injections were performed in both grid and barrier configurations.

Shallow groundwater occurs in unconsolidated soil and weathered bedrock. Bedrock occurs at relatively shallow depths [2 to 6 meters (m) below ground surface (bgs)] and consists of fissile shale interlayered with thin beds of siltstone, sandstone and limestone. The overlying unconsolidated material is weathered shale and residual silty clay soil derived from shale. The depth to water in the shallow zone beneath the site varies from less than 1 to about 2 m bgs.
The overall site cleanup goal was to reduce CVOCs to below the USEPA Maximum Contaminant Levels (MCLs). In the primary source area, the goal was to reduce the contaminant mass to a level that would support the success of plume wide treatment using 3DMe®.

The first round of injections was completed in the fall of 2012 by AST Environmental Inc. (AST). Planned supplemental injections of both BOS 100® and 3DMe® were performed in late 2013/early 2014. In addition to the 3DMe®, sodium bicarbonate (for pH buffering) and BioDechlor Inoculum (BDI®) were added in strategic locations to optimize the remedial effort based on observations from the first injection event (lowering of pH and daughter product accumulation).

Installation of the BOS 100® resulted in rapid reduction of TCE (98%) with comparable reductions in cis-1,2-Dichloroethene (DCE) and Vinyl Chloride (VC). The TCE concentrations in the Secondary Source and Dilute Plume areas treated with 3DMe® were reduced 98-99.9%. Daughter product concentrations initially increased as expected, but have been reduced to an average of 89% and 37% for DCE and VC respectively.

BOS 100® consists of activated granular carbon impregnated with reactive iron. BOS 100® "traps" groundwater CVOCs by adsorption onto the carbon granules and holds the contaminants in close proximity to the reactive iron to be "treated" by chemical reduction.

Biostimulation of naturally-occurring bacteria was performed by injecting 3DMe®, a multi-component amendment containing both quick-release and slow-release components 3DMe® is comprised of a patented molecular structure containing oleic acids and lactates/polylactates which are molecularly bound to one another.

Session 14: Treatment of Solid Waste, Vapor/Gas Mitigation and Phtoremediation

A Review of Process and Performance of Coal Combustion Wastes Recycling

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Coal combustion wastes are by-products generated during the combustion of coal for energy production in thermal power plants. Fly ash, bottom ash and boiler slags are accepted as coal combustion wastes. Currently, coal consumption has increased to 7503.3 million tonnes worldwide annually and is expected to increase up to 8950 million tonnes in 2035 (http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review, 2014). China is the largest coal consumer in the world and accounts for 50.3% of the world coal consumption in 2013. The top 10 coal consumer, after China are the USA (11.9%), India (8.5%), Japan (3.4%), Russian Federation (2.4%), South Africa (2.3%), South Korea (2.1%), Germany (2.1%), Poland (1.5), Indonesia (1.4%) and Australia (1.2%).

In the lights of above data it can be estimated that nearly 750 million tons of coal combustion wastes are produced worldwide each year. 5-15 % of them are found in the form of coarse bottom ash and boiler slags while 85-95 % are found in the form of fine fly ash (Yao et al., 2015). A small percentage of the coal combustion wastes have been utilized mainly in cement and other construction products. Other uses include road base construction, soil amendment, zeolite synthesis, bricks and tiles production, mine filling and filler in polymers (Oz et al., 2009). However these are not enough for complete utilization of coal combustion wastes generated. The rest of the material is discharged to the ash ponds, lagoons or landfills as in the form of thin slurry or in dry form, which both lead to ecological and environmental problems. The potential environmental risks of coal combustion waste disposal are: surface and ground water contamination (leaching), sudden release of liquid wastes, windblown, radioactivity and mercury pollution.

Recycling and reuse are the alternative to disposal as well as economic and environmental benefit. Utilization rates of coal combustion rates are vary from country to country for example in the USA 50%, over 90% for EU and 60% for India. This rate is 67% for China but it was claimed in a report that actual recycling for coal combustion wastes in China is only 30% (http://www.greenpeace.org/usa/en/media-center/reports/The-True-Cost-of-Coal-Ash-in-China).

In this work, an attempt was made to review coal combustion wastes recycling.

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Removal of Metallic Contaminants from Solid Wastes: Closing the Circle

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Lab4U is a research group composed of members of both university (the faculty of Engineering Technology of the KU Leuven) and university college (the group of Management & Technology of the University College Leuven-Limburg). In close collaboration with the industry, they combine the expertise of both institutes to develop new technologies and/or conduct feasibility studies for existing industrial (bio) chemical processes. The research group focuses on the purification of wastewater and process water, the remediation and recovery of contaminated soils and waste and the miniaturization and intensification of (bio) chemical production processes. Technologies include the use of ultrasound, microwaves, green chemicals and micro-flow reactors.

Current industrial washing plants for the removal of metallic contaminants, are not able to purify all soils or other solid wastes to the desired degree; residual concentrations of contaminants in some solids are still too high and landfilling or incineration is necessary. The use of dissolution enhancing chemicals during this process leads to an improved release of the contaminants. The removing efficiency of different additives was tested in the presence of absence of ultrasound waves by both lab scale and semi-pilot scale experiments. Combination of chemicals in combination to acoustic energy (ultrasound) increases the efficiency significant, up to 10 times. After the washing process the former waste can often be used as secondary raw material. However, the contamination is transferred to the washing solution and a sustainable solution is needed for metal removal from this solution and reuse of it at the same time.

To this end, a Microbial Electrolysis Cell (MEC) in which bacterial processes produce (a part of) the energy needed to remove the metals from the washing solution is investigated as a promising method with low environmental impact compared to conventional electrolysis or chemical precipitation. In the metallurgical MEC electrons are generated by bacteria that grow as a pollutant-degrading biofilm on the bio-anode surface, and transported through an external circuit to the (bio-) cathode where they can be used for metal reduction/recuperation. Except for Cu^{2+}, input of additional voltage from an external power source is needed for the metal reduction. Experiments are conducted on laboratory scale with real-life mixed metal containing waste water from soil washing installations. It is investigated which metals can be removed in presence of the chemicals in an energy-efficient way from the real-life waste water, which yield is achieved and with which purity the metals are recovered. The recovered metals can then re-enter the industrial world.

By combining different technologies a closed circle for solids, water and metals can be achieved.

Design and Performance Evaluation of Vapor Mitigation System for a Large PCE Plume Site

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In the past several years, the issue of intrusion of contaminated soil gas into residential, commercial, and industrial buildings has gained much attention in the scientific community and environmental industry. Complex sub-slab environments (i.e., slab on grade foundations, anisotropic heterogeneous geologic settings, etc.) and varying fate and partitioning behavior of organic contaminants compel a need to develop innovative vapor intrusion mitigation strategies. In addition, vapor mitigation (VM) systems are now being designed to actively collect and treat contaminated vapors, providing added remedial benefit while also protecting human health. However, with active systems in complex sub-slab environments come challenges that must be considered during design. This presentation describes innovative VM design approaches that can be utilized to address such complexities. This presentation also provides a case study of a VM system that was implemented to mitigate intrusion of volatile organic compounds (VOCs) from beneath a slab on grade foundation of an active facility in northern New Jersey.

A vapor intrusion and indoor air assessment performed at the subject site revealed concentrations of tetrachloroethylene (PCE) that exceeded the New Jersey Department of Environmental Protection (NJDEP) indoor air rapid action levels. Pilot testing and pneumatic modeling were performed to determine VM design parameters. Site constraints included shallow water table, a sub-slab silty-clay formation with low air intrinsic permeability, and anisotropic geologic conditions. The VM system extraction points, manifold, process equipment, and control interlocks were innovatively designed to provide adequate vacuum propagation and vapor capture, while also reducing the amount of water collected during operation. Since its startup in September 2014, the system has been operating successfully. Indoor air sampling data collected in January 2015 indicate that the system is effectively providing vapor intrusion mitigation throughout the building footprint. The system operation has also resulted in substantial remedial progress at the site with notable vapor-phase VOC mass removal.

Alternanthera Bettzickiana (Regel) G. Nicholson: A Potential Phytoremediator of Heavy Metal Contaminated Soils: Growth and Physiological Response

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Heavy metals represent a major environmental pollutant and caused toxicities in plants and humans through entering the food chain which requires affordable strategies for their remediation. The current study was aimed to investigate several morphological, physiological and biochemical responses of *Alternanthera Bettzickiana* (Regel) G.Nicholson plant to elevated concentrations of cadmium (Cd) and lead (Pb) (up to 2.0 mM) grown in soil separately. Results showed that *A. bettzickiana* was able to accumulate Cd and Pb in different plant parts and total uptake of both metals was higher in shoots than roots. Plant growth, biomass and photosynthetic pigments iincreased with increasing metal concentrations, up to 1.0 mM, in the soil and then decreased with higher metal levels. Lower concentrations (0.5 and 1.0 mM) of metals increased the activities of superoxide dismutase (SOD, peroxidase (POD), catalase (CAT) and ascorbate peroxidase (APX) while decreased at higher metal levels (2.0 mM). Leaf and root electrolyte leakage (EL), malondialdehyde (MDA) and hydrogen peroxide (H_2O_2) contents decreased at lower metal levels ($\leq$ 1.0 mM) in a dose dependent manner while increased at higher levels. Overall, the present results clearly signify the potential of *A. bettzickiana* plant towards Cd and Pb tolerance and accumulation especially at lower metal levels and highlighted that this plant might be used in phytoremediation of Cd and Pb contaminated soils. Although *bettzickiana* could not be used as Cd and Pb hyper-accumulator, plant can grow normally under Cd and Pb stress and considerable amount of heavy metals could be extracted by harvesting the plants.

Keywords: antioxidants, heavy metal, oxidative stress, Phytoremediation, tolerance

Landfill Gas Mitigation Design Considerations for Site Redevelopment

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Over the past two decades, the United States has seen a substantial increase in development on closed municipal-waste landfills. The construction value of these projects easily exceeds billions of dollars in addition to the substantial end-use benefits such as tax revenues and new jobs. Redeveloping landfills is particularly challenging not only because of the issues associated with cleanup, but also because of the environmental and geotechnical issues of building on refuse. Landfill gas containing elevated levels of methane poses a significant risk of fire, explosion and odor. Other landfill gases such as sulfur-based corrosives like hydrogen sulfide and volatile organic compound vapors also pose significant exposure risks to human health, safety and the environment.

To be effective, design strategies for mitigating landfill gas, must incorporate the site's architectural, structural, and geotechnical features. Applying pilot testing and pneumatic air-flow computational modeling tools is good engineering practice to determine key parameters, including air intrinsic permeability of the refuse, radius of influence, well network, desired air-flow rates, vacuum propagation, and pore-air volume exchanges, for cost-effective designs and more reliable predictions of the mitigation system performance. Detailed evaluation of long-term remedial benefits, potential refuse settlement, seismic hazards, fire and explosion hazards, and corrosive-gas impacts on the system constructability and performance should also be performed during the design phase.

The redevelopment of closed landfills will continue for years to come. Although redevelopment of landfills holds great potential, the means and methods used to design and implement gas mitigation systems are such that human health, safety and the environment are protected for the life of the project.

This paper describes a framework of design considerations for developing effective landfill gas mitigation strategies for site redevelopment. A case study of a landfill gas mitigation system design and engineering concepts that were developed for a proposed development at a formerly closed landfill is presented.

Mannitol Alleviates Chromium Toxicity in Wheat Plants in Relation to Growth, Yield, Stimulationof Anti-Oxidative Enzymes, Oxidative Stress and Cr Uptake in Sand and Soil Media

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Chromium (Cr) is one of the most phyto-toxic metals in the agricultural soils and its concentration is continuously increasing mainly through anthropogenic activities. Little is known on the role of mannitol on plant growth and physiology under metal stress. The aim of this study was to investigate the mechanism of growth amelioration and antioxidant enzyme activities in Cr-stressed wheat (*Triticum aestivum* L. cv. Lasani 2008) by exogenously applied mannitol (M). For this, wheat seedlings were planted in pots containing soil or sand and subjected to increasing Cr concentration (0, 0.25 and 0.5 mM) in the form of of $K_2Cr_2O_7$ with and without foliar application of 100 mM mannitol. Plants were harvested after four months and data regarding growth characteristics, biomass, photosynthetic pigments, and antioxidant enzymes were recorded. Mannitol application increased plant biomass, photosynthetic pigments and antioxidant enzymes while decreased Cr uptake and accumulation in plants as compared to Cr treatments alone. In this study, we observed that M applied exogenously to Cr-stressed wheat plants, which normally cannot synthesize M, improved their Cr tolerance by increasing growth, photosynthetic pigments and enhancing activities of antioxidant enzymes and by decreasing Cr uptake and translocation in wheat plants. It is concluded that M could be used to grow crops on marginally contaminated soils for which separate remediation techniques are time consuming and not cost effective.

Keywords: anthropogenic, antioxidant enzymes, chromium, growth, mannitol, photosynthesis